

BASIC WATER TREATMENT OPERATION

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**Ministry
of the
Environment**

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INTRODUCTION

The *Basic Water Treatment Operation* course based on this manual covers five days at the Ministry of the Environment training facilities. The course consists of lecture-discussions and hands-on training in water treatment plant operations.

The principal objective of the course is to introduce the operator to the fundamentals of plant operations. The lesson objectives are clearly indicated at the beginning of each topic, and tell the operator what he should know or do after having covered that topic. In order to successfully complete this course, an overall average of 70% is required.

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SUBJECT:

WATER CHARACTERISTICS

TOPIC: 1

Bacteriological
Characteristics

OBJECTIVES:

The trainee will be able to

1. Understand the need for the production of the highest quality of water.
2. Recall the sources of bacteria in the water.
3. Recall the nature and size of bacteria.
4. Give the reason for the use of "indicator" bacteria.
5. Name 2 techniques for lab examination of samples to determine bacteriological quality.
6. Determine the minimum number of samples required and their frequency for raw water and distribution systems.
7. Understand the importance of correct Bacteriological Procedures.
8. Recall three important criteria for effective destruction of bacteria.

BACTERIOLOGICAL CHARACTERISTICS

GENERAL

The job of keeping our drinking water safe has become a vital and increasingly difficult task. The war against pollution is only beginning. Municipalities still discharge untreated or partially treated sewage into the streams, and industry aggravates the problem by dumping an ever-changing variety of chemical contaminants.

The water works, and particularly those in the larger and more populated areas, are now confronted with problems that did not exist until a few years ago. If the water treatment works are to function properly, it is essential that their personnel know the sources of contamination that are or may become a danger to the quality of the water in their plant. The amount of close supervision required in operating a plant is materially increased in those areas where known sources of contamination are present.

Sources of industrial waste pollution as well as upstream sewage treatment plants should be known to the personnel of water works plants. An ever-changing variety of chemical and other waste discharges are reaching water works plants. As a result, most water works in industrial areas have some type of waste control treatment available. Radiological, anionic detergent, pesticide, phenolic and other organic wastes from industrial sources and from land run-off have brought new problems that are often difficult to solve. Industries are sometimes located extremely close to water works intakes, increasing the need for careful supervision in the water works plant.

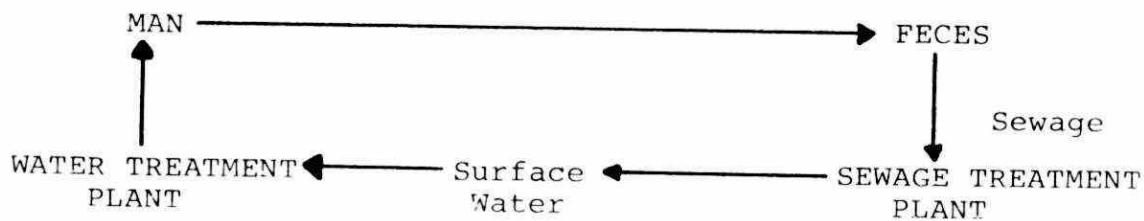
While some analytical results have more importance than others, all have certain limiting values established to protect the health of the individual and the well-being of the community.

These limiting values, or "Drinking Water Objectives", will be discussed with a view of their role in attaining the above goals. These objectives were formally adopted by the former OWRC in 1964 and updated by amendment in 1967. The discussion will be divided into two sections: *bacteriological* (Topic 1), *physical* and *chemical* characteristics (Topic 2).

BACTERIA IN WATER

General

There are many sources of bacteria present in any body of water (see Figure 1-1). Many of them make up the "normal flora" of the water, whilst others may enter the water by being washed off vegetation, soil, farmlands, etc., or by sewage plant and sewer effluents. In water treatment, the bacteria which are the most important grow and are excreted in the intestinal tract of man and animals; the "pollution cycle" shows why this is so.



In the intestinal contents of man and animals some bacteria are normal flora. One group of these is the "coliform group", made up of total coliforms and fecal coliforms; another kind are the fecal streptococci; *Pseudomonas* and *Clostridia* are other kinds. All these kinds are non-pathogenic and always present in the intestinal contents.

Persons or animals infected with the so-called "enteric diseases" (typhoid, dysentery, cholera, etc.) carry and excrete

millions of the disease-producing bacteria, along with the normal intestinal flora. These bacteria may gain access to the surface or well water (as outlined in Figure 1-1), which is used for drinking. If the water is consumed untreated, or improperly treated, an epidemic of the enteric disease could result.

The various kinds of bacteria are recognized by:

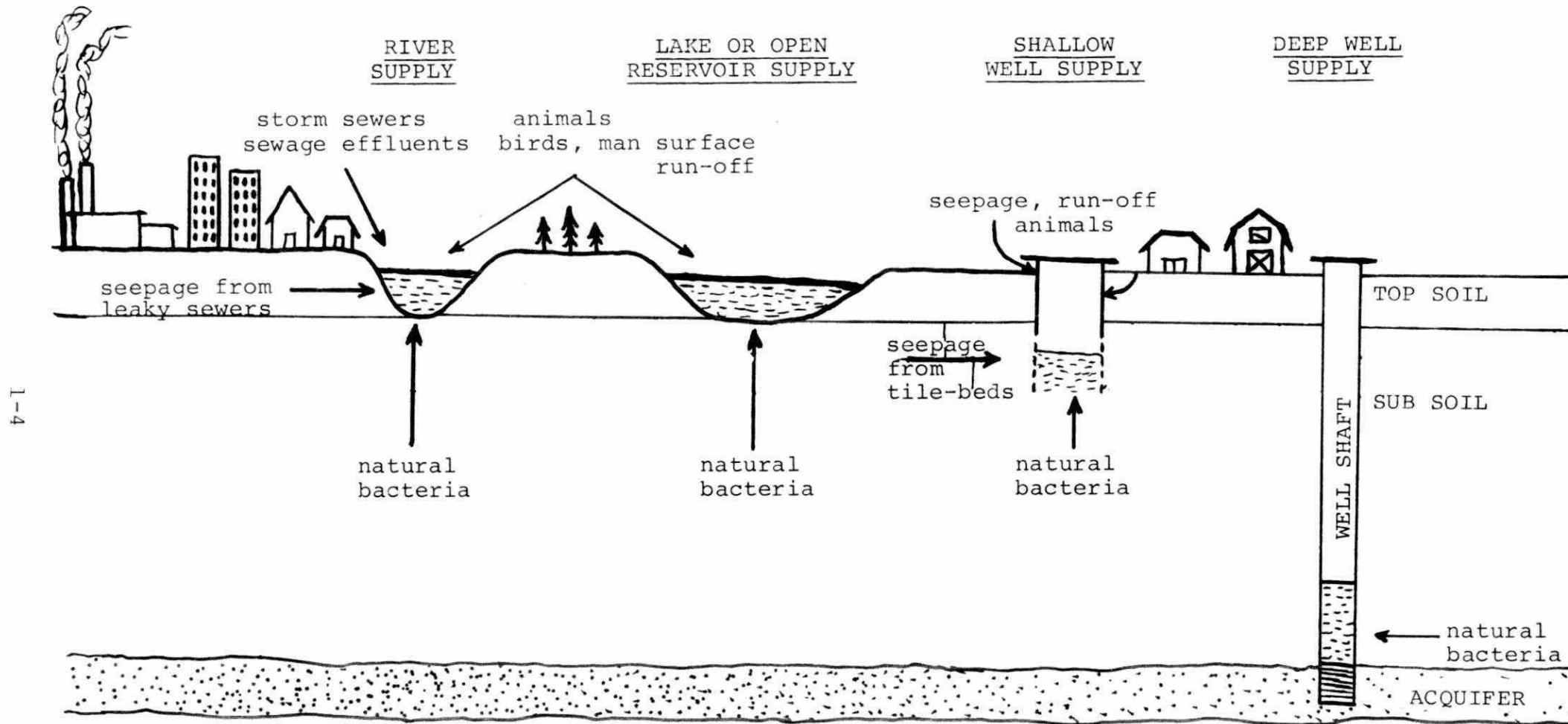
1. The shape and arrangement of the cells.
2. Their metabolic properties - the food which they use and how they use it.
3. Their pathogenic properties - whether or not they produce disease in man or animals .

Bacteria are found everywhere, and the kinds and numbers vary from place to place, depending upon the environmental conditions. Some kinds of bacteria are always present in certain places; the common occurrence of one or more kinds of bacteria in a particular place is described as the "normal flora" of that place or environment. Thus, *E coli* is a kind of bacterium that is always found in the intestine of man, and is part of the "normal flora" of the intestine.

The great majority of bacteria are harmless to man, and perform a great number of useful functions e.g. the formation of compost. Only a few kinds are harmful to man, and those which are important in potable water production will be considered. The way in which they can gain entry to a water supply, and the steps that must be taken to eliminate them, will be discussed.

FIGURE 1-1

SOURCES OF CONTAMINATION OF WATER SUPPLIES



NATURE OF BACTERIA (Figure 1-2)

Size

Bacteria are one-celled and may be seen only with the aid of a microscope; they are viewed, normally only after some staining procedure, using a magnification of about 1,000 times. Their size range is from about 0.5μ to 6μ or 7μ , but most are from 1-3 ($1\mu = 1/1,000$ mm).

Algae, on the other hand, can be examined using a magnification of only 100 to 200 times, and they are green-coloured because they contain chlorophyll.

Shape

There are only two basic shapes of bacteria cells:

1. Spherical forms called cocci,
2. Rod-shaped forms called bacilli

although there are variations in the two basic shapes, such as filaments or bean-shaped cocci, etc.

Arrangement

The bacterial cells may either be found singly, or may be attached to one another to form chains or clumps of cells; some kinds of bacteria are capable of independent movements.

Reproduction

Bacteria can multiply, usually very rapidly, by one cell splitting into two. The speed of multiplication depends greatly

on environmental conditions; for example, an increase in temperature usually results in an increase in the speed of multiplication.

WATER TREATMENT

Since it is difficult to prevent the entry of pathogenic bacteria into a drinking water source, the water must be treated to destroy the pathogenic bacteria before it is delivered to the consumer. At first, treatment of water supplies was begun to prevent the spread of waterborne diseases. Chlorination was introduced in 1910, and was soon followed by additional treatment to produce water free from suspended solids, colour, and unpleasant tastes and odours. Coagulation, flocculation, sedimentation by storage, and filtration, which remove particulate matter from raw water, also removes bacteria. Certain bacteria, however, will remain in suspension so chlorination (or in some places, ozonation) is required to produce a water safe for drinking. *Badly treated or impure waters with high turbidities cannot be completely disinfected by chlorination. It is important to understand that bacteria can be protected from chlorine by particulate and organic matter.* When used as a final process, chlorination should be regarded only as an *additional* safeguard. It should be applied to waters which are clear and of good organic quality.

To destroy bacteria effectively, three things are important:

1. The amount of chlorine added.
2. The contact time allowed between the chlorine and bacteria.
3. The amount of protective particulate matter present in the water.

Figure 1-2 NATURE OF BACTERIA

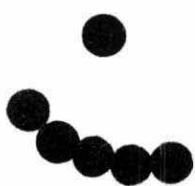
Size

Scale: $\frac{1}{4}$ " = 1 μ = $\frac{1}{1000}$ mm

Shape

COCCUS FORMS

Single



Chain
e.g. *Streptococcus*



Clump
e.g. *Staphylococcus*

uniform size 1μ diameter

BACILLUS FORMS

Single



Chain
e.g. *Streptobacillus*



Clump
e.g. Typhoid Bacillus

GRIDS FORMS



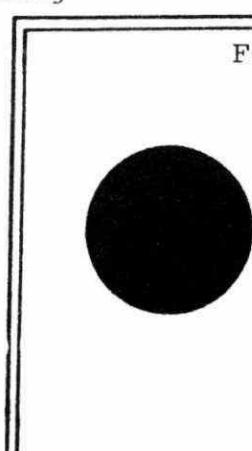
e.g. *Leptospira*

.2 - .75 μ wide 5 - 25 μ
long

FOR COMPARISON

ALGAE

e.g. Chlorella



Because the efficiency of the chlorine process (disinfection) can vary, due to many reasons e.g. breakthrough of particulate matter, change in pH of the incoming water, an increased pollution load, etc., the finished water must be monitored bacteriologically. Such monitoring is designed to ensure that the disinfection stage was sufficient to kill all pathogens.

Coliforms are normal flora in the intestine, and they are also more resistant to chlorine than the bacteria that cause enteric disease. If all the coliforms are eliminated in the disinfection process, then all the disease bacteria have also been destroyed; where coliforms can still be found, some disease-producers may also have survived. When the coliform group of organisms is present, the water has not been treated properly to destroy all the pathogenic bacteria; the water must be considered as unfit to drink until the treatment has been improved. The coliform group is thus used as an indicator by which the efficiency of the water treatment can be determined. Other indicator bacteria are also being used, on a large scale, as tests for them are perfected.

This indirect, indicator test is used because analysis for the coliform indicator bacteria is faster, easier and safer to perform than direct analysis for the disease producers.

IMPORTANCE OF AN ADEQUATE BACTERIOLOGICAL SAMPLING PROGRAM

Communities have been relatively free of attack for generations but the possibility of a water-borne epidemic still exists. Periodically over the past few years, epidemics related to contaminated water supplies have been reported. For example, in November and December of 1959, the community of Keene, New Hampshire, experienced a typhoid epidemic. The source of the infection was finally traced, after considerable investigation,

to the Keene water supply. This community's water supply consisted of an unspoiled mountain watershed and a good, slow sand filter treatment plant. All of these factors, combined with careful water distribution practices, would indicate that the consumer was receiving a safe quality water. Yet overnight the water system turned into a distributor of the organisms of deadly typhoid fever.

A curious combination of circumstances led to the typhoid infection. A wood cutter, working in the watershed area without authorization, was discovered to be a typhoid carrier. His waste had been washed into the city's water during unusual flooding in *October*.

The epidemic at its height affected 19 people and was known to have taken the life of one person. The city officials were suddenly made aware that the city was in the business of producing a product - and they had a legal and moral responsibility to guarantee its safety. The Council was faced with the alternatives either of paying \$67,000 in settlement of claims or allowing these claimants to sue the city. One attorney estimated that the costs of going to court could have risen as high as one-half million dollars (\$500,000).

For at least a decade prior to the epidemic local health and water authorities, the city's consulting engineer, and the State Board of Health, had all recommended the installation and continuous operation of chlorination facilities. The City Council repeatedly denied the requests. The result: Keene paid several times the cost of the installation and operation of chlorination facilities, and derived no benefits from it. Further, the Water Department suffered a considerable loss of face.

This example points out that there will always be a need for continued responsible supervision at any water treatment plant to ensure that the quality of the water will not be affected and that there will be no return to the water-borne epidemics of another era. The first public health requirement in water works treatment is responsible supervision to assure proper standards in maintaining water quality.

Frequency of Sampling

Contamination is often intermittent and may not be revealed by analyzing a single sample. A single sample shows only the conditions at the time of sampling; a satisfactory result does not guarantee that conditions will remain the same. Therefore, a series of samples taken regularly over a period of time is required. See Appendix A for Sampling Procedures.

TABLE 1-1 Frequency of Sample Collection

Population Served	Minimum Number of Samples per Month	Minimum Frequency of Sampling Intervals
Up to 100,000	8 + 1 per 1,000 of population	weekly
Over 100,000	100 + 1 per 10,000 of population	several times per week

The number of samples determined with the use of the above table shall not include plant effluents whether treated or otherwise.

In systems utilizing surface water or treated ground water, samples shall be taken and analyzed from the raw water source and the point at which treated water enters the distribution system with at least the same frequency as that for the distribution system. In addition, the operator must ensure that the chemical disinfection process is functioning properly at all times.

In systems utilizing untreated ground water, samples shall be taken and examined not less than once per week from the source and all points at which water enters the distribution system.

The total number of samples collected monthly may consist of those examined by the Ministry, other government laboratories, water works authorities or even by commercial laboratories, if the analytical results are acceptable to the Ministry. Special samples shall not be included in the total number of samples required above.

TESTING PROCEDURES

Coliforms and other indicators may be tested for by any one, or all three of the following methods:

1. *The Presence/Absence Test (P/A) shows only the presence or absence of a bacterial group in 50 or 100 ml of sample but not how many there are. It is used for coliforms and also fluorescent pseudomonads and clostridia.*

This method is presently being used on nearly all municipal water samples submitted to the Ministry Laboratory. The test offers a distinct advantage over others since the results are known within 18-24 hours. If the presence of indicator bacteria

is shown, other tests are conducted to determine the types. The test on treated water or distribution samples should show the absence of indicator bacteria.

2. The *Membrane Filtration Test* (MF), is often run in conjunction with the P/A test, so that the number of coliform organisms in a sample can be counted. This is normally used in the routine analyses of raw and treated water, and can be used to count fecal streptococci and fecal coliforms.
3. The *Most Probable Number Test* (MPN). This test allows a statistical calculation of the number of coliform organisms present in a water sample. It is useful where the MF procedure cannot be used, such as for turbid water and sewage, which would block millipore filters.

No bacteriological analysis of water, however exact, can take the place of a complete knowledge of the conditions at the sources of supply and throughout the distribution system. Every water supply should be regularly inspected from source to distribution taps, and sampling should be repeated under various seasonal conditions, especially after heavy rainfall. It should be emphasized that when sanitary inspection indicates a water, as distributed, to be subject to pollution, the water should be considered suspect irrespective of the results of bacteriological analyses of water leaving the treatment plant.

LIMITS FOR DISTRIBUTION SYSTEMS

Bacteriological

The Most Probable Number (MPN), the Membrane Filter (MF), or the Presence-Absence (P-A) tests may be used to determine coliform and fecal coliform populations for the purpose of assessing drinking water quality. It is noted that the aforementioned methods have varying sensitivities and occasionally when samples are tested in parallel by more than one method, one method will produce positive results whereas the other will not. This may occur more frequently in treated water samples, where stressed or debilitated organisms may be present, which will be recovered only by the most sensitive method. In all cases where discrepancies such as this are found, results from the method producing the positive will be used.

The Presence-Absence test also permits screening for other bacteria indicators of water quality.

Limits for the various indicator bacteria and the action required if the limits are exceeded are described below. These limits have been divided into two sections in recognition of the fact that indicator organisms may appear as a result of a sudden, serious pollution event; or because of a less and gradual deterioration of water treatment or distribution system maintenance practices; or because of accidental contamination of the sample(s); or because of introduced contamination from a cross-connection; or because the sampling tap was insufficiently flushed prior to taking the sample.

Indicators of Unsafe Water Quality

Total coliform bacteria, determined by the MF and MPN method, should not be present in densities of 5 or more organisms

per 100 ml, or when determined by the P-A method, they should not give positive results within 48 hours.

Fecal coliforms should not be detected in any sample by any of the methods.

If these limits are exceeded, the water quality is judged unsafe. The operating authority will begin an investigation to determine the probable reason for contamination. The regional staff of the Ministry will be notified immediately by telephone for collection of special samples. Should the circumstances warrant it, the Medical Officer of Health (MOH) may be contacted by MOE Regional Staff in the event of results showing a high level of contamination in the system, and corrective action initiated immediately.

Special Samples

Special sampling shall consist of a minimum of 3 samples to be collected for each positive sample site; one sample should be collected at the affected site, one at an adjacent location on the same distribution line and a third sample should be collected some distance upstream on a feeder line toward the water source. These samples must be marked 'special' on the laboratory submission sheet. The chlorine residuals at the time of sampling for each site must be marked on the laboratory submission sheet beside each sampling location. The collection of three special samples is considered a minimum number for each adverse sampling site. The measurement of the chlorine residuals in the vicinity of the positive sampling sites may assist in the definition of the extent of the contamination within the distribution system, and may be used to determine the appropriate corrective action.

If the results of the special samples also exceed the limits, for "Unsafe Water Quality", the MOH will be notified by the MOE Regional staff, and the following further action must be taken.

The chlorine dose will be immediately increased, together with flushing to ensure a total residual of at least 1.0 mg/L or a free chlorine residual of 0.2 mg/L to all points in the affected part(s) of the distribution system.

If satisfactory chlorine residuals are not detected in the affected part(s) of the distribution system or if the circumstances warrant, the issuance of a BOIL WATER advisory by the Medical Officer of health may be made. Corrective measures along with thorough resampling and analysis of the entire water system should continue until the limits are no longer exceeded.

Indicators of Poor Water

1. *Total Coliform, Aeromonas and Clostridium Perfringens*

When total coliform bacteria are present at levels below 5 organisms per 100 ml by MF or MPN tests, or when positive P-A results for total coliform bacteria occur after 48 hours incubation, and/or when *Aeromonas* or *Clostridium perfringens* are detected, they should not occur in more than 25% of the samples of a single submission, nor in successive submissions from the same sampling site.

Total coliforms at levels below 5 organisms per 100 ml by MF or MPN tests, or producing positive P-A results for total coliform bacteria after 48 hours incubation should

not occur in more than 10% of the samples submitted in any one month. *Aeromonas* and *C. perfringens* should not occur in more than 15% of the samples submitted in any one month.

2. *Pseudomonas aeruginosa*, *Staphylococcus aureus* and members of the Fecal *Streptococcus* Group. These organisms should not be detected in any sample.

3. Standard Plate Counts

The routine analysis for coliform bacteria should periodically be supplemented by standard plate counts (SPC). This should be done by either testing some of the samples for each submission or by testing all the samples in a given submission on a quarterly basis. Samples for SPC analysis should preferably be kept refrigerated and transported on ice, and be received and analyzed within 24 h of collection.

The limit for SPC (35°C , 48 h) is 500 organisms per mL (based on a geometric mean of 5 or more samples). When these limits are exceeded, more intensive monitoring of the distribution system should be carried out.

Suggested Sampling Procedures and Corrective Measures for Poor Water Quality

1. Total Coliform, Aeromonas and Clostridium Perfringens
 - a) When the limits are exceeded from a single sample submission, repeat samples may be requested from the sites yielding the positive results along with simultaneous

* Samples for SPC analysis should preferably be kept refrigerated and transported on ice, and be received and analyzed within 24 hours of collection.

determination of the chlorine residuals. (These repeat samples should be so marked on the submission sheet along with the chlorine result).

If any of the repeat samples show the presence of any of the indicators of poor water quality, the regional staff of the Ministry should be notified by telephone and special samples (see Page 14) should be collected at the positive locations.

If the results of the special samples are also positive for poor water quality indicators, corrective action may be indicated, such as instituting chlorination, increasing chlorine dosage, flushing and, if necessary, foam swabbing.

- b) When the limits are only exceeded for the monthly sample totals, the operating authority should undertake a review of distribution system maintenance procedures, chlorine residual and plant operations.

2: Pseudomonas aeruginosa, Staphylococcus aureus and Members of the Fecal Streptococcus Group

When positive samples are found repeat samples may be requested from the affected sites along with the simultaneous determination of chlorine residuals.

If any of the repeat samples are positive, the Regional staff of the Ministry should be notified by telephone and special samples should be collected. If these samples are also positive, the appropriate corrective action, as outlined in 1 a) may be indicated.

3. Standard Plate Counts

If this limit is exceeded, repeat samples may be requested. If the limit is exceeded in the repeat sampling, the regional staff of the Ministry should be notified by Laboratory staff by telephone and corrective action carried out as in 1 a).

INTERPRETATION OF RESULTS

The interpretation of the routine bacteriological reports is perhaps the most important aspect. Results are usually expressed as the number of bacteria present per 100 ml of sample. P/A tests are reported using the words "present" or "absent".

Water delivered to the consumer ("finished" water) is expected to conform to certain limits and objectives. Where some bacteria reach undesirable levels, the pattern of the results can sometimes be used to decide the corrective action to be taken. See Table 1-2.

"Coliforms" are found in the intestine, but can also occur on soils and vegetation. "Fecal coliforms" form a sub-group within total coliforms but, as indicated by their name, are found "only" in human and animal fecal waste; since they die out more rapidly than coliforms, their presence should be considered as a sure indication of recent fecal pollution, calling for immediate action. The repeated presence of total coliforms, in the absence of fecal coliforms, may indicate the growth of these bacteria on organic materials in the pipe or on debris, and investigation should be made into possible sources.

"Fecal Streptococci" as detected by the P/A test, can indicate that fecal pollution has occurred, but some members of this group can also be found in soil and on vegetation. They

Table 1-2 BACTERIA INDICATORS OF SEWAGE CONTAMINATION IN WATER TREATMENT

	TOTAL	FECAL COLIFORM	FECAL STREPTOCOCCI	PSEUDOMONAS AERUGINOSA	FLUORESCENT PSEUDOMONAS	CLOSTRIDIA
Test	MF or P/A	MF or P/A	MF or P/A	P/A	P/A	P/A
Reported	Numbers/ml + or 1	OR Numbers/ml + or -	OR Numbers/ml + or -	OR + or 1	+ or -	+ or -
Maximum Allowable Limit	500/ml	Absent	Absent	Absent	Few	15% samples positive
Source	Sewage, Soil Vegetation	Fresh sewage	Sewage, soil Vegetation	Sewage, water	Soil, Water Sewage	Old Sewage, Manure
Indication	a) Possible contamination with sewage	Definite contamination with fresh sewage	Possible contamination with sewage	Improper treatment	Improper treatment	Improper treatment prior to chlorination
	b) Improper treatment		Improper treatment	Deteriorated Conditions	Deteriorated Conditions	Deteriorated Conditions
	d) Growth in system		Insufficient chlorine	Insufficient chlorine	Insufficient chlorine	

can be used as indicators of possible fecal contamination or deteriorated water treatment practice; their isolation may be particularly useful where coliforms are present, but fecal coliforms cannot be found. They are more resistant to chlorination than coliforms and tend to survive longer. Absence of these bacteria show that disinfection has been adequate.

"*Pseudomonas aeruginosa*" occurs in sewage and can be pathogenic under certain specific circumstances, although not usually when ingested by mouth. Since it shows some resistance to chlorination, there is growing pressure to include a test for it, and other fluorescent pseudomonads, in the routine examination of potable water. As with the fecal streptocci, the appearance of pseudomonads may indicate that the chlorine dosage is too low, and a correction is necessary.

"*Clostridia*" are a group of organisms which can be used as indicators of pollution with sewage, since they are present in both sewage and manure. These organisms produce very resistant bodies called spores; on account of these, the bacteria can survive in water long after all other indicator organisms have disappeared. These indicators are useful in water supplies that are not sampled frequently. In such cases, chance sampling may show the water to be free from coliforms (which will have died out) but the water could have been dangerously contaminated at intervals in between. *Clostridia* would probably be isolated in these circumstances and would indicate a need for closer surveillance. The spores are not destroyed by normal chlorination practices, and repeated positive clostridial tests in treated water may indicate that treatment was inadequate before final chlorination (e.g. improper filtration).

Treating water supplies properly and effectively not only ensures freedom from pathogenic organisms, but also yields

beneficial side effects. A finished water with a turbidity of 1 unit or less and a free chlorine residual of 0.3 ppm will meet bacteriological standards, and organic material and debris will not enter the lines. "Every effort should be made to achieve these levels". Where debris enters the lines, bacterial growth and slime formation can occur, with taste and odour and red water problems developing. Correct pH control and/or treatment for the presence of iron will prevent the deposit of rust and iron materials in the line.

SAMPLING PROCEDURES

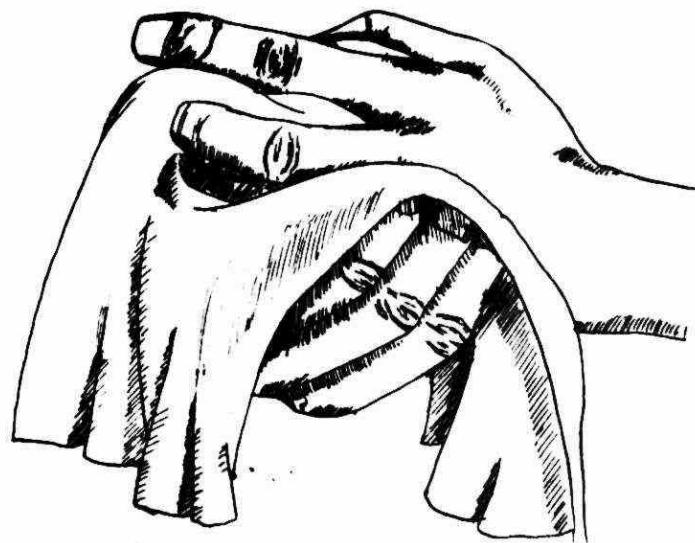
The water sample must represent only the condition of the water *at the time of collection*, so the following precautions are necessary. Reliable results depend on using proper sampling techniques and the necessary care when collecting the sample.

1. The bottles must be sterile (bacteria free), obtained from the Shipping and Receiving Department of the Ministry's laboratory.
2. The sampler's hands should be washed thoroughly and dried before handling the bottle, to be sure that no bacteria are introduced from that source. When the bottle cap is removed, the inside edges of the cap and the mouth of the bottle must not be handled, and the cap should not be put down.
3. From a tap, the water should be allowed to run freely for at least *two minutes before the bottle cap is removed*. When samples are taken from a well, river, stream, lake or open tanks, the bottle should be submerged below the surface. Sampling devices, such as a copper wire around the neck of the bottle, should be flame-sterilized before being used. In all cases, the bottle should be filled so as to leave enough air space for proper mixing before analysis.
4. For sampling water that contains chlorine, a bottle containing sodium thiosulphate should be used. The thiosulphate neutralizes any remaining chlorine and prevents it from continuing to kill off any remaining bacteria during shipment of the sample.

Figure 1-3 SAMPLING PROCEDURES



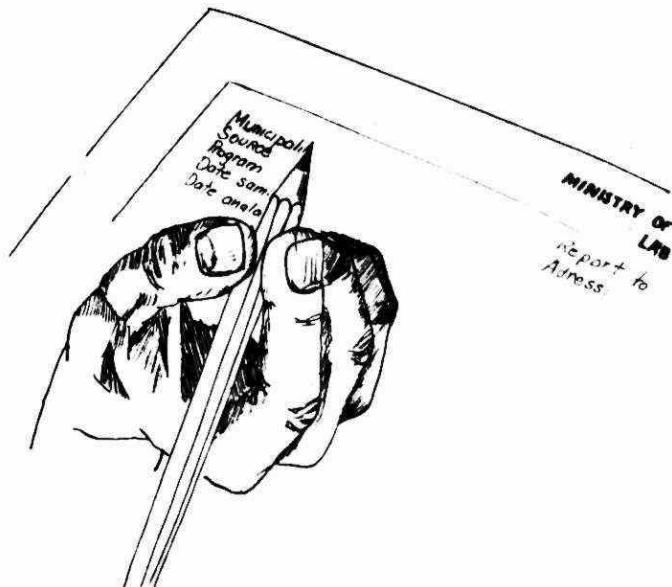
1. Wash hands thoroughly.



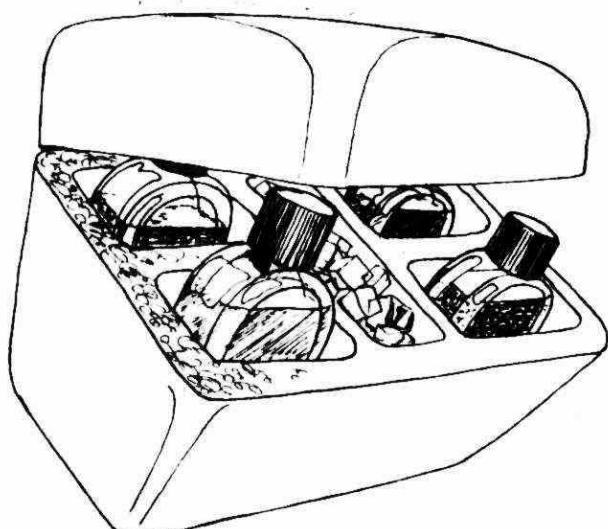
2. Dry hands well.



3. Allow tap to run for a few minutes. Fill bottle, hold cap as shown.



4. Fill out Sample Report in full.



5. Ship Samples packed in ice.

5. The sample report should be filled out in full, giving all the particulars of the sample, and information which may assist the analyzer in the selection of the best possible combination of tests for the purpose.
6. The water samples should be shipped to the Ministry laboratory immediately, and should arrive within 24 hours. Refrigeration is desirable, since an increase in temperature in the sample may encourage multiplication of the bacteria and result in an erroneously high count. Special containers are now available for maintaining low temperature during shipment.

Bacteriological samples over 3 days old are not tested as there is too much change in population and a completely false picture of the water at the time of sampling could be obtained.

The responsibility for taking the required number of samples lies with the operating authority, whether it be a municipality or an individual who owns a private water supply.

SUBJECT:

WATER CHARACTERISTICS

TOPIC: 2

Physical and Chemical
Characteristics

OBJECTIVES:

The Trainee will be able to:

1. Identify four physical characteristics of water.
2. Identify the causes of taste and odours in water.
3. Give Ministry objectives for acceptable levels of
 - a. Turbidity
 - b. Colour
4. Define the terms:
 - a. Maximum Acceptable Concentration (MAC)
 - b. Interim Maximum Acceptable Concentration (IMAC)
 - c. Maximum Desirable Concentration (MDC)
5. Define the terms:
 - a. Alkalinity
 - b. Hardness
 - c. pH
6. Identify the problems associated with high levels of the following chemical constituents; chlorides, iron, manganese, nitrates, sulphates.

PHYSICAL AND CHEMICAL CHARACTERISTICS

PHYSICAL CHARACTERISTICS

Physical tests do not measure the safety of a water supply, but they do give an indication of its acceptability to the consumers. This is why the objectives adopted by the Ministry to govern the physical characteristics of the water are not as strict as those required for bacteriological control. The physical qualities which concern waterworks operators are:

- 1) Turbidity
- 2) Colour
- 3) Taste and Odour
- 4) Temperature

Substances producing turbidity are often inorganic while those causing taste, odour and colour are generally organic compounds.

Turbidity, colour and taste and odour requirements can be attained by properly designed and operated treatment plants and distribution systems. Failure to meet the requirements indicates either inadequate treatment facilities or improper operation of the system.

Turbidity

Turbidity in water is caused by the presence of suspended matter such as clay, silt, colloidal particles, plankton and other microscopic organisms. Turbidity can serve as a source of nutrients for micro-organisms and interfere with their enumeration. The adsorptive properties of suspended particles can lead to concentration of heavy metal ions and biocides in turbid waters. Turbidity has also been related to trihalomethane formation in chlorinated water. But the most important health effect of turbidity is its interference with disinfection and with the maintenance of a chlorine residual. Viable coliform bacteria have been detected in waters with turbidities higher than 3.8 even in the presence of free chlorine residuals of up to 0.5 mg/L and after a contact time in excess of 30 minutes, and outbreaks of disease traced to chlorinated water supplies have been associated with high turbidity. To incorporate a safety factor, a maximum acceptable turbidity level of one turbidity unit (1 Formazin turbidity unit - FTU or 1 nephelometric turbidity unit - NTU) has therefore been established.

If left untreated, the smaller turbidity particles would pass through a rapid sand filter while the larger turbidity particles would plug the media of the filter causing short filter runs.

Table 2-1 illustrates the relative times required to settle various types of turbidity.

TABLE 2-1

SETTLING TIME - PARTICLES

Diameter of Particle (Microns)	Order of Size	Approximate Time
		Required to Settle 10 cm
100	Fine Sand	12.4 s
10	Silt	10.7 min
1	Bacteria	17.9 h
0.1	Colloidal Particle	74.7 d

1 000 microns = 1 mm

Colour

Colour in drinking water may be due to the presence of natural or synthetic organic substances as well as certain metallic ions such as those of iron, manganese and copper. Metals tend to impart only apparent colour which is usually removable by filtration or centrifugation; on the other hand, organic materials particularly those derived from naturally occurring substances, may contribute to true colour which is not readily removed by filtration or centrifugation. Colour becomes noticeable to consumers at levels greater than the maximum desirable 5 true colour units (ICU - platinum cobalt scale).

The colouring matter is composed of humic, tannic and fulvic acid compounds which cause the yellowish-brown tea colour. The general properties of these compounds are:

1) Size in the range of 0.003 to 0.02 microns.

In comparison, colloidal turbidity particles are in the range of 0.5 to 0.15 microns.

2) The colour particles are negatively charged due to the chemical groups attached to the humic, tannic and fulvic substances.

True colour levels commonly found in Ontario vary from:

0 - 5	TCU	Great Lakes
30 - 60	TCU	Ontario River & Southern Ontario Rivers
100 - 150	TCU	Northern Ontario Lakes & Rivers

There are exceptions to this guide but generally the most highly coloured waters are found in Northern Ontario.

Taste & Odour

Taste and odour are intimately related, and consumers frequently mistake odours for tastes. In general, the sense of

taste is most useful in detecting the ionic, inorganic constituents of drinking water, whereas the sense of smell is most useful in detecting covalent, organic constituents. Taste and odour problems constitute the largest category of consumer complaints. Changes in the taste of drinking water may indicate possible contamination of the raw water supply, treatment inadequacies, or contamination of the distribution system. A numerical limit for taste has not been specified because there is no objective method for the measurement of taste and because there is considerable variation among consumers as to which tastes are acceptable. Water provided for public consumption should have an inoffensive taste.

Although an odour can be attributed to a specific substance, it is usually impractical and often impossible to isolate and identify the odour-producing chemical. Evaluation of this parameter is therefore dependent on individual senses of smell but because odour cannot be objectively measured, a numerical limit has not been specified. The odour of drinking water should be inoffensive.

It is almost impossible to determine and classify the different types of odours that can be experienced. Table 2-2 gives a qualitative description of some of the more common odours found in water supplies. It can be used as a guide to classify the type and determine the source of odour.

Taste and odours in water supplies may result from any one or

TABLE 2-2

THRESHOLD ODOR DILUTION CHART

ML. OF SAMPLE	ML. OF ODOR- FREE WATER	THRESHOLD NUMBER	ML. OF SAMPLE	ML. OF ODOR- FREE WATER	THRESHOLD NUMBER
200	0	1	12	188	17
140	60	1.4	8.3	192	24
100	100	2	5.7	194	35
70	130	3	4.0	196	50
50	150	4	2.8	197	70
35	165	6	2.0	198	100
25	175	8	1.4	200	140
17	183	12	1.0	200	200

TYPICAL TASTES AND ODORS FOUND IN POTABLE WATER¹

Alcohol	Flat	*Melting ice
*Algae	Gaseous	*Pig pen
*Aromatic	Gasoline	Oily
Burnt leather	*Grassy	*Peaty
Chlorinous	Irony	*Ripe cucumber
Chlorophenol	*Humic acid	*Rivery
Creosote	*Hydrogen sulfide	Sewage
*Decaying vegetation	Limy	*Stagnant
*Decomposition	Medicinal	*Swampy
Disagreeable	*Marshy	Sweetish
*Earthy	*Moldy	Tarry
*Fishy	*Musty	*Woody

* Refers to tastes and odours of natural origin

a combination of conditions. They are usually caused by the presence of dissolved gases and organic substances. In some cases, inorganic compounds such as those of mineral and metallic salts may impart tastes to the water at very low concentrations. However, organic substances are likely to be responsible for the presence of odours. Sources of material causing taste and odour problems may be:

- 1) Dissolved gases i.e. hydrogen sulphide, chlorine.
- 2) Biological growths such as algae, and slimes.
- 3) By-products of decaying algae and vegetation.
- 4) Contaminants from sewage effluents and surface runoffs.
- 5) Contaminants from industrial waste discharges.
- 6) Growths of nuisance organisms in the distribution system i.e. iron bacteria.
- 7) Contact of water with painted surfaces such as bituminous linings of water pipes and storage tanks.
- 8) Dissolved minerals i.e. chlorides, manganese, sulphates.

The variation in tastes and odours caused by algae has a wide range. The odours may be classified as follows:

- 1) Aromatic Odour - These odours are very often described as a particular flower or vegetable. Organisms in small numbers can produce these odours.
- 2) Fishy Odour - These odours are often produced by the same algae that produce the aromatic odours. The organisms are usually present in much larger numbers.
- 3) Grassy Odours - This odour is very common when the green algae are present in large numbers.
- 4) Musty and Earthy Odour - The musty odour in some waters is very often encountered in the presence of certain blue-green algae.

The control and prevention of many tastes and odours caused by algae may be with the use of:

- 1) Chlorine (Cl_2)
- 2) Granular Activated Carbon (GAC)
- 3) Potassium Permanganate (KMnO_4)
- 4) Microstraining

Temperature

It is desirable that the temperature of drinking water be less than 15° C; the palatability of water is enhanced by its coolness. Low water temperatures offer a number of other benefits. A temperature below 15° C will tend to reduce the growth of nuisance organisms and hence minimize associated taste, colour, odour and corrosion problems. Low temperature facilitates maintenance of a free chlorine residual by reducing the rates of reaction leading to hypochlorous acid removal. Although low temperature can decrease the efficiency of water treatment processes, this effect may be compensated for by altering the amounts of chemicals used in treatment; low temperature is not a bar to the production of water of an acceptable quality.

Higher temperatures make water less palatable and reduces its suitability for air conditioning purposes. Temperatures above 27° C are unsuitable and above 32° C render the water unfit for public use.

CHEMICAL CHARACTERISTICS

Normally, analyses for chemical constituents are only needed twice a year. But if the supply is suspected of containing undesirable materials, periodic determinations for the suspected toxicant or material should be carried out more frequently (every month for example). On the other hand, where experience, examination and results indicate that particular substances are

consistently absent from a water supply or are below levels of concern, then, with the approval of the Ministry, semi-annual examinations for these substances may be omitted.

Limits for Chemical Constituents

The chemical constituent concentrations in water is broken down into three categories:

- 1) Maximum Acceptable Concentration (MAC)
- 2) Interim Maximum Acceptable Concentration (IMAC)
- 3) Maximum Desirable Concentration (MDC)

Maximum Acceptable Concentration (MAC)

This term is used for limits applied to substances above which there are known or suspected adverse health effects. The presence in a drinking water of a substance at a level in excess of its maximum acceptable concentration shall be grounds for rejection of the water unless effective treatment is available. The length of time the maximum acceptable concentration can be exceeded without injury to health will depend on the nature and concentration of the contaminant, however, no drinking water can be permitted to exceed these limits continuously.

Interim Maximum Acceptable Concentration (I.M.A.C)

This term is used to describe limits for substances of

TABLE 2-3
Maximum Acceptable Concentrations
Parameters Related to Health

Parameter*	Concentration (mg/L)
Arsenic	0.05
Barium	1.0
Boron	5.0
Cadmium	0.005
Chromium	0.05
Cyanide (Free)	0.2
Fluoride	2.4
Lead	0.05
Mercury	0.001
Nitrate (as N)**	10.0
Nitrite (as N)	1.0
Nitrilotriacetic Acid (NTA)	0.05
Pesticides	
(Aldrin + Dieldrin	0.0007
(Carbaryl	0.07
(Chlordane	0.007
(DDT	0.03
(Diazinon	0.014
(Endrin	0.0002
*** (Heptachlor + Heptachlor Epoxide	0.003
(Lindane	0.004
(Methoxyclor	0.1
(Methyl Parathion	0.007
(Parathion	0.035
(Toxaphene	0.005
2,4-D	0.1
2,4,5-TP	0.01
Selenium	0.01
Silver	0.05
Trihalomethanes****	0.35
Turbidity	1 FTU or NTU

- * Unless otherwise stated the limits for each substance refer to the sum of all forms present.
- ** Where both nitrate and nitrite are present, the total nitrate plus nitrite-nitrogen should not exceed 10 mg/L.
- *** When more than one of these pesticides is present, the "total pesticides" shall not exceed the sum of their MAC's or 0.1 mg/L whichever is the lesser.
- **** The term "trihalomethanes" comprises chloroform, bromodichloromethane, chlorodibromo-methane and bromoform and their concentrations as determined by the gas sparge or purge equivalent method (i.e. actual concentration) should not exceed 0.35 mg/L at any time.

TABLE 2-4
 Interim Maximum Acceptable Concentrations
 Parameters Related to Health

<u>Parameter</u>	<u>Concentration (mg/L)</u>
Polychlorinated Biphenyls	0.003
Uranium	0.02

TABLE 2-5
Maximum Desirable Concentrations
Parameters Related to Asthetic Quality

Parameter	Concentration*
Chloride	250
Colour	5 (TCU)**
Copper	1.0
Iron	0.3
Manganese	0.05
Methane	3 L/m ³
Odour	Inoffensive
Organic Nitrogen***	0.15
Phenols	0.002
Sulphate	500
Sulphide	Inoffensive
Taste	Inoffensive
Temperature	15° C
Total Dissolved Solids	500
Total Organic Carbon	5.0
Zinc	5.0

* Unless otherwise indicated, the maximum desirable concentrations are expressed in mg/L.

** True Colour Units.

*** Total kjeldahl nitrogen minus ammonia nitrogen.

current concern with known chronic effects in mammals and for which there are no established maximum acceptable concentrations. Although toxicological, epidemiological and health data are available for such substances the data are subject to public and scientific debate before agreement on a maximum acceptable concentration. The I.M.A.C. will generally be a conservative value subject to change as more precise information becomes available.

When a substance is detected at a concentration above its I.M.A.C., it will signal the need for more sampling and investigation.

Maximum Desirable Concentration (MDC)

This term is used for limits on substances which, when present at concentrations above the limits, are either aesthetically objectionable to an appreciable number of consumers or may interfere with good water quality control practices. These limits should not be exceeded whenever a more suitable supply or treatment process is, or can be made available at a reasonable cost.

The chemical substances shown in Table 2-5 should not be present in a water supply in excess of the concentrations indicated where, in the judgement of the Ministry, other more suitable supplies are, or can be made available.

Application of Limits

The establishment of a limit should not be regarded as implying approval of the degradation of a high quality supply to the specified level. The limits described herein have been derived from the best information currently available; however, the development of drinking water objectives is an on-going process. Scientific knowledge of the complex inter-relationships that determine water quality continue to increase as does the understanding of the physiological effects of the substances present in water. Also, man continues to introduce new chemical substances into the environment, many of which may contaminate drinking water supplies. It therefore may be necessary to revise the established limits as new and more significant data become available.

The limits apply to all water supply systems which provide water for domestic purposes and serve more than five private residences or are capable of supplying water at a rate greater than 0.5 litres per second. Although a water supply serving five or fewer private residences is excluded from the application of the limits, it is desirable that the quality of water from these supplies should not be inferior to that supplied to the public in general.

Problems Associated with Chemical Constituents

Alkalinity

A limit on alkalinity may be necessary to ensure that it is sufficient to enable optimum floc formation during coagulation processes, but not so high as to cause gastrointestinal discomfort or irritation and that it affords a proper chemical balance so that the water is neither corrosive nor incrusting. Generally, in water analysis, alkalinity is expressed in terms of equivalent amount of calcium carbonate. An undersaturation with respect to calcium carbonate may promote reactions causing iron pickup and the consequent development of "red water". An oversaturation with respect to calcium carbonate may result in incrustations on utensils and in service pipes, and water heaters.

Alkalinity in the range of 30 to 500 mg/L as calcium carbonate is generally acceptable, but it does not guarantee that problems due to this characteristic within this range, will not occur. The point of chemical stability with respect to alkalinity, may be highly variable in different waters and, from time to time, in the same water. It is therefore suggested that each water be evaluated on its own merit with respect to alkalinity taking into consideration such factors as the relative amounts of carbonate, bicarbonate and hydroxyl ions, total dissolved solids, calcium and pH.

Aluminum

Aluminum is the third most abundant element in nature which accounts for its presence in practically all natural waters.

When alum (hydrated aluminum sulphate) is used as a coagulant in water treatment, the measurement of residual aluminum in the treated water is important, not only to indicate the efficiency of the treatment process, but also because too high a residual aluminum can result in:

- a) distribution system coating with consequent increased energy requirements,
- b) interferences for certain industrial processes, and
- c) after-flocculation leading to consumer complaints.

At present, there is no evidence that aluminum is physiologically harmful and no limit has been specified. A useful guideline to avoid the above problems to maintain a residual below 0.1 mg/L as Al in the water leaving the plant.

Arsenic

The toxicity of arsenic is well known. Except in areas close to natural, agricultural or industrial sources of arsenic contamination, arsenic is present at very low concentrations in

surface waters. A number of disorders have been associated with the intake of arsenic in drinking water, but the lowest concentration at which symptoms develop has not been clearly established. There is, however, no evidence of any illness associated with the ingestion of water containing arsenic at the maximum acceptable concentration, 0.05 mg/L. Some studies have suggested that arsenic is either a carcinogen or co-carcinogen, and it is therefore advisable that the level of arsenic in drinking water be as low as possible.

Asbestos

Asbestos is a general term applied to certain minerals that form soft, flexible fibers in metamorphic rocks. It may be introduced into natural waters by the dissolution of asbestos-containing rocks and from industrial sources. The use of asbestos-cement (A-C) pipe in the distribution system of water supplies may contribute to the asbestos content of drinking water if the aggressiveness of the water is not under control. However, aggressive waters can be easily made non-aggressive with simple treatment modification. There is a lack of reliable historical data on levels of asbestos in water because of the unavailability until recently of a standardized method for asbestos determinations.

Optimized conventional water treatment practices are considered effective in the reduction of asbestos in potable

water. Evidence of a health risk associated with ingestion of asbestos has not been found. The absence of a reliable historical data base for asbestos in water, precludes an epidemiological assessment of human health effects from ingested asbestos; hence a maximum acceptable concentration for asbestos cannot be reasonably established at this time. However, prudence would suggest keeping asbestos levels in drinking water as low as possible.

Barium

Barium is a relatively common constituent of the earths crust, but in aquatic systems, it is seldom present at concentrations greater than 1 mg/L. Ingestion of barium can result in serious physiological effects. In man, a single dose of 125 mg/Kg of soluble barium can elicit an acute toxic response. At very low levels, the toxicological effects of barium are not as well understood. The maximum acceptable concentration, 1.0 mg/L is considered adequate to provide a satisfactory factor for safety.

Boron

The most likely boron species in water is boric acid. In humans, a number of acute boron poisonings have resulted from the use of borates as antiseptic agents and from accidental ingestion, but the levels of exposure were much higher than would be encountered in drinking water. Infants, the elderly, and

individuals with kidney diseases are the groups most susceptible to the toxic effects of boron compounds. The maximum acceptable concentration, 5.0 mg/L is considered to provide a sufficient safety factor from boron intoxication. Drinking water supplies generally have boron concentrations of less than 1 mg/L.

Cadmium

Cadmium is a highly toxic element. Water can be contaminated with cadmium from natural or industrial sources. Cadmium compounds used in plumbing materials may also be a significant source of contamination of drinking water during distribution. For non-occupationally exposed individuals, food is the main source of cadmium intake.

Since it would be difficult to reduce cadmium intake from food, intake from water should be as low as possible. Daily consumption of two litres of water containing the maximum acceptable concentration of cadmium, 0.005 mg/L would result in the ingestion of only about 15 per cent of the tolerable intake.

Chloride

Chloride levels in the body are well regulated and in reasonable concentrations, chloride is not harmful to humans. At concentrations above 250 mg/L, chloride may impart an undesirable taste to water and beverages prepared from water. The maximum desirable concentration of chloride in drinking water is therefore

set at 250 mg/L.

Chromium

Trivalent chromium, the most commonly naturally occurring state of chromium is not considered to be toxic. However, if present in raw water it may oxidize to hexavalent chromium during chlorination. Known harmful effects of chromium in man are attributed primarily to this hexavalent form. Drinking water containing chromium at the maximum acceptable concentration 0.05 mg/L has not resulted in any known harmful effects to the health of man or animals.

Copper

At levels in excess of the maximum desirable concentration, 1.0 mg/L copper may produce a taste which is objectionable to consumers. Although the intake of large doses of copper has resulted in adverse health effects, the levels at which this occurs are much higher than the maximum desirable concentration. Copper is an essential element in human metabolism.

Cyanide

Cyanides are widely used in industry. and industrial effluents are the major sources of the cyanide contamination of water. Cyanide at doses of less than 10 mg is readily detoxified to thiocyanate in the body. The lethal toxic effects of cyanide

usually occur only when this detoxification mechanism is overwhelmed. The maximum acceptable concentration for free cyanide, 0.2 mg/L therefore provides a safety factor of approximately 25. Adequate chlorination for cyanide oxidation will reduce cyanide to a level below this limit.

Fluoride

The presence of small amounts of fluoride in drinking water leads to a substantial reduction in the incidence of dental caries, particularly among children. Where fluoridation is practiced the fluoride-concentration recommended is 1.2 mg/L.

Excessive fluoride intake produces dental fluorosis, a condition characterized by mottling of tooth enamel. The maximum acceptable concentration for naturally occurring fluoride is 2.4 mg/L.

Hardness

Hardness can have significant aesthetic and economic effects. Water hardness is caused by dissolved polyvalent metallic ions, principally calcium and magnesium, and is expressed as the equivalent quantity of calcium carbonate. On heating, hard waters have a tendency to form scale deposits and can also result in excessive soap consumption. Soft water, on the other hand may result in corrosion of water pipes. Depending on the interaction of other factors such as pH and alkalinity, hardness levels

between 80 and 100 mg/L as calcium carbonate (CaCO_3) are considered to provide an acceptable balance between corrosion and incrustation. Water supplies with a hardness greater than 200 mg/L are considered poor but have been tolerated by consumers; those in excess of 500 mg/L are unacceptable for most domestic purposes.

It is well to note that water softening by sodium-ion exchange will introduce additional sodium into drinking water and this additional sodium may constitute a significant percentage of sodium intake if a consumer is required to adhere to a prescribed diet limiting the intake of sodium.

However for the majority of those not on a restricted sodium intake, the additional sodium would not constitute a very significant percentage of the total sodium intake from all sources.

Iron

Excessive levels of iron in drinking water supplies are objectionable for a number of reasons. At levels higher than the maximum desirable concentration 0.3 mg/L, iron may impart a brownish colour to laundered goods; it may produce a bitter, astringent taste in water and beverages; and the precipitation of iron may impart a reddish-brown colour to the water. Excessive iron can also promote the growth of iron bacteria in water mains and service pipes.

Lead

Ingestion of lead can result in serious illness or death. Lead is a cumulative poison, and long-term ingestions of relatively low levels can be injurious to health. The minimum dose at which adverse human health effects occur as a result of chronic exposure has not been precisely established. There is, however, no evidence of any illness associated with the ingestion of drinking water containing lead at the maximum acceptable concentration, 0.05 mg/L. A significant source of lead in municipal drinking waters, particularly in soft or aggressive water areas, may be old lead service connections.

Manganese

Like iron, manganese is objectionable in water supplies because it stains laundry and at excessive concentrations causes undesirable tastes in beverages. Difficulties may commence in some waters with a concentration as low as 0.05 mg/L. Manganese may also encourage the buildup of slimy coatings in piping which can slough off as black precipitates.

Mercury

Mercury is a toxic element and serves no known beneficial physiological function in man: alkyl compounds of mercury are the most toxic to man, producing illness, irreversible neurological

damage, or death from the ingestion of milligram quantities. Food is the major source of human exposure to mercury and fish which bioconcentrate organic mercury in their tissues, are the most important food source of mercury. Long-term daily ingestion of approximately 0.25 mg of mercury as methyl mercury has caused the onset of neurological symptoms. The maximum acceptable concentration for mercury in drinking water, 0.001 mg/L provides a considerable margin of safety. Mercury levels in both source water and tap water are generally well below this level.

Methane

Methane contamination may be a problem in well water supplies. Methane occurs naturally in ground water and acts as a stimulant of organic fouling conditions in the distribution system. Methane is not represented in dissolved organic carbon (DOC) analyses and its carbonaceous content is therefore additional to any DOC result. Experience has shown that methane at the maximum desirable concentration 3 L/m^3 , can be controlled by chlorination alone, given a clean distribution system. Also methane under pressure will come out of solution when the pressure is reduced, resulting in a cloudy appearance in freshly drawn water but this should not be a problem at methane levels less than the limit. If methane is allowed to accumulate in confined areas, e.g. well pits or parts of distribution systems and plumbing, an explosion hazard may develop.

Nitrate

The maximum acceptable concentration of nitrates in drinking water, 10 mg/L as N, is based on consideration of the relationship between infantile methemoglobinemia and the presence of nitrate in drinking water. The nitrate ion is not directly responsible for this disease but must first be reduced to nitrite ion by intestinal bacteria. The nitrite ion reacts with the iron of hemoglobin to produce an altered hemoglobin, methemoglobin which is unable to transfer oxygen and thus the tissues become oxygen-starved. Therefore the occurrence of nitrate ion in water commands caution.

Nitrate poisoning from drinking water appears to be restricted to susceptible infants; older children and adults drinking the same water are unaffected. Most water-related cases of methemoglobinemia have been associated with the use of water containing more than 10 mg/L nitrate as N or 45 mg/L nitrate. In Canada, no cases of this disease have been reported where nitrate concentration was consistently less than the maximum acceptable concentration. Where both nitrate and nitrite are present, the total nitrate plus nitrite-nitrogen concentration should not exceed 10 mg/L. In areas where the nitrate content of water is known to exceed the maximum acceptable concentration, the public should be informed by the appropriate health authority of the potential dangers of using the water for infant feeding.

Nitrilotriacetic Acid

Nitrilotriacetic acid (NTA) has many industrial applications but its main use is a "builder" in laundry detergents. Most of the NTA used is therefore eventually disposed of in domestic sewage, and it is consequently a potential contaminant of drinking water supplies. In general, the toxicity of NTA is very low, however, an increased incidence of urinary tract tumours was found in rats and mice that had been fed very large doses of NTA. Risk assessment using these data, together with the relatively poor absorption of NTA by man, suggests that the risk associated with a NTA level in drinking water of 0.05 mg/L is negligible.

Nitrite

The maximum acceptable concentration of nitrite in drinking water, 1.0 mg/L as N, is based, as with nitrate, on the relationship between nitrite in water and the incidence of infantile methemoglobinemia. Nitrite is quickly oxidized to nitrate and is therefore seldom present in surface waters in significant concentrations. Nitrite may occur in ground water sources, however, if chlorination is practiced, it will be oxidized to nitrate. The contribution of nitrite from drinking water to the total daily intake would be negligible for most public water supplies.

Organic Nitrogen

Excess organic nitrogen (as represented by the total kjeldahl nitrogen concentration minus the ammonia nitrogen concentration) may be associated with organic fouling in the distribution system and some types of chlorine-enhanced taste problems.

Nitrogen-containing organics are measured in dissolved organic carbon (DOC) determinations but, because of the nutritive value of nitrogen, their contribution to biological fouling is greater than would be suggested from DOC analysis; organic nitrogen at the maximum desirable concentration of 0.15 mg/L. Organic nitrogen compounds frequently contain amine groups which can react with chlorine. Certain chlorinated organic nitrogen compounds may be responsible for flavour problems that are similar to those from chlorophenol tastes and odours. Taste and odour problems have been usually associated with organic nitrogen levels of 0.15 to 0.2 mg/L or greater.

Organic Substances

Organic chemical substances are present to some degree in all municipal water supplies. The sources of these chemicals are diverse. Industrial and municipal waste, urban and rural runoff, and the natural decomposition of biological matter may all contribute to the organic content of water. The organic chemical contaminants of drinking water may be divided into two classes on the basis of origin: natural or synthetic.

The major portion of organics in most waters is of natural origin. These natural substances consist primarily of undefined or poorly defined humic and fulvic materials and other products of organic decomposition. The constituents have presumably always been present in drinking water and are not in themselves likely to present a health hazard. Maximum acceptable concentrations have therefore not been set for any naturally occurring organic chemicals.

Synthetic organic chemicals in drinking water can be the result of certain water treatment practices or the direct contamination of the raw water from point and non-point sources of pollution. Normally the contribution of the synthetic component to the total organic content is small, but it may be significant in highly polluted waters. Most are present at such low concentrations that they appear to pose no substantial additional threat to human health. However, the majority of synthetic organic chemicals that have been identified in drinking water have not been examined exhaustively for potential health effects; as a matter of prudence the concentrations of such materials should therefore be as low as possible.

Maximum acceptable concentrations have been set only for a few of those organic chemicals that could conceivably be present in drinking water at levels that pose a human health hazard.

Pesticides

Three groups of pesticides are important in water quality evaluation; chlorinated hydrocarbons and their derivatives; chlorophenoxy herbicides; and the cholinesterase-inhibiting compounds that include the organo-phosphorus chemicals and carbamates. Chlorinated hydrocarbon compounds tend to persist in the environment. Some cause either direct health effects or indirect effects due to biological concentration in man's food chain. Organo-phosphorus compounds and the cholinergic carbamates, although they may have high acute toxicity to mammals, hydrolyse rapidly in the aquatic environment to harmless or less-harmful products. As a matter of prudence it is desirable that drinking water be free of pesticides and every effort should be made to prevent pesticide pollution of raw water sources.

Maximum acceptable concentrations have been derived for those pesticides for which acceptable daily intake (A.D.I.) values have been published by the World Health Organization or the U.S. Environmental Protection Agency. Daily consumption of two litres of water containing the maximum acceptable concentration of a specific pesticide, would result in the ingestion of not more than 20 per cent of A.D.I. for that pesticide. It is recognized that the list of pesticides in Table 2-3 is not comprehensive and constitutes only a small fraction of such substances available in Ontario. Local circumstances may require the use of a pesticide for which guidelines have been established. Monitoring for

the presence of such substances in drinking water may, therefore, be deemed desirable. When a pesticide not listed in Table 2-3 , is detected in a water supply, advice should be obtained from the appropriate health authority.

pH

The range of pH in public water systems may have a variety of economic, health and indirect aesthetic effects. The principal objective in controlling pH is to produce water that minimizes corrosion and incrustation. At pH levels above 8.5, mineral incrustations and bitter tastes can occur. Corrosion effects are commonly associated with pH levels below 6.5; elevated levels of certain undesirable chemical substances may result from the corrosion of specific types of pipe. With pH levels above 8.0, there is also a progressive decrease in the efficiency of chlorine disinfection and alum coagulation processes. The desirable range for drinking water pH is 6.5 to 8.5.

Phenols

The maximum desirable concentration of phenolic substances in drinking water is 0.002 mg/L. This limit has been set primarily to prevent the occurrence of undesirable taste and odours, particularly in chlorinated water. Chlorophenols may be produced during the chlorination process and have very low taste and odour threshold concentrations; the taste threshold of some

chlorophenols may in fact be less than the maximum desirable concentration. Phenol levels in Ontario drinking water supplies are generally less than 0.001 mg/L.

Polychlorinated Biphenyls

Polychlorinated biphenyls (PCBs) are among the most ubiquitous and persistent pollutants in the global ecosystem. In the past, PCBs have been marketed extensively for a wide variety of purposes but their use in Canada is currently being phased out. There is some evidence which suggests that PCBs may be carcinogenic, however, the data are insufficient to permit establishment of a maximum acceptable concentration of PCBs in drinking water. The available information does suggest that drinking water contain PCB's at a concentration of 0.003 mg/L would not pose a health risk. Therefore, an interim limit of 0.003 mg/L is recommended. Alternative supplies of drinking water should be considered if this limit is exceeded.

Selenium

The symptoms of selenium intoxication in man are rather ill defined. Also, it is difficult to establish levels of selenium that can be considered toxic because of the complex interrelationships between selenium and dietary constituents such as protein, vitamin E, and other trace elements. Food is the main source of selenium intake for non-occupationally exposed

individuals. Drinking water containing selenium at the maximum acceptable concentration, 0.01 mg/L would be the source of only 10 per cent of total selenium intake; the maximum acceptable concentration is therefore considered to provide a satisfactory factor of safety from known adverse effects.

Silver

Concentrations of silver in water are generally very low. Elevated levels of silver in drinking water can arise however, from the use of silver as a water disinfectant. Ingestion of excessive amounts of silver may result in argyria, a condition characterized by a blue-grey discolouration of the skin, eyes and mucous membranes. The exact quantity of silver required to produce argyria is unknown, but it is believed to be in the order of 1000 mg. The maximum acceptable concentration, 0.05mg/L therefore incorporates a substantial margin of safety.

Sodium

Sodium is not considered to be toxic metal, and in excess of 10 grams per day is consumed by normal adults without apparent adverse effect. In addition, the average intake of sodium from water is only a small fraction of that consumed in a normal diet. A maximum acceptable concentration for sodium in drinking water has therefore not been specified. Persons suffering from hypertension or congestive heart failure may require a

sodium-restricted diet in which case the intake of sodium from drinking water could become significant. It is therefore recommended that the measurement of sodium levels be included in routine monitoring programs of water supplies. The Medical Officer of Health should be notified when the sodium concentration exceeds 20 mg/L, so that this information may be disseminated to local physicians.

Sulphates

The maximum desirable concentration of sulphate in drinking water is 500 mg/L. At levels above this concentration, sulphate can have a laxative effect; however, regular users adapt to high levels of sulphate in drinking water and problems from this effect are usually only experienced by transients and new consumers. The presence of sulphate in drinking water may result in a noticeable taste, the taste threshold concentration depending on associated cations. High levels of sulphate may be associated with calcium, which may contribute to the formation of scale in boilers and heat exchangers. In addition, they may also contribute to the presence of hydrogen sulphide in some types of waters.

Sulphide

Although ingestion of large quantities of sulphide has produced toxic effects in humans, it is unlikely that an individual would consume a harmful dose in drinking water because

of the associated unpleasant taste and odour. Sulphide is also undesirable in water supplies because in association with soluble iron, it produces black stain on laundered items and black deposits on pipes and fixtures. Sulphide is oxidized to sulphate in well-aerated waters and consequently sulphide levels in public supplies are usually very low. Sulphide levels (expressed as hydrogen sulphide) in water should be inoffensive to the sense of smell and taste.

Total Dissolved Solids

The term "total dissolved solids" (TDS), refers mainly to the inorganic substances dissolved in water. The principal constituents of TDS are chloride, sulphates, calcium, magnesium and bicarbonates. The effects of TDS on drinking water quality depend on the levels of its individual components; excessive hardness, taste, mineral deposition, or corrosion are common properties of highly mineralized water. The palatability of drinking water with a TDS level less than 500 mg/L is generally considered to be good.

Total Organic Carbon

The dissolved organic carbon test measures almost all of the dissolved organic constituents of a water, while the total organic carbon procedure may also include fine suspended particulates and compounds absorbed and any other particulates entering the

analytical stream.

High levels of organic carbon in water may result either from excess naturally occurring matter or from man-derived sources, showing a frequent association with colour, taste, odour and turbidity difficulties. Elevated organic levels, although not necessarily a hazard in themselves, may provide precursors for the formation of potentially more harmful contaminants during chlorination. Additionally, high organic levels may develop a potential hazard of conveying biocides and heavy metal ions throughout natural water sources and past water treatment processes.

It should be noted, however, that some waters, even with a low organic content, may still contain minute but hazardous concentrations of toxic organic chemicals. Therefore TOC or DOC is not a direct indicator of possible adverse health effects, and a maximum acceptable concentration for TOC is not specified. However, related to an increased risk of water quality deterioration during storage following accepted treatment practices, a maximum desirable concentration of 5.0 mg/L for TOC (equivalent to clear water DOC) has been derived.

Trihalomethanes

The trihalomethanes are the most widely occurring synthetic-organics found in drinking water and they also appear at the highest concentrations. Four trihalomethanes have been

detected in drinking water: chloroform, bromodichloromethane, chlorodibromomethane and bromoform. The principal source of trihalomethanes in drinking water is the chemical interaction of chlorine added for disinfection, with humic and fulvic substances that occur naturally in the raw water. It has been demonstrated in rodents that the ingestion of large doses of chloroform results in the development of malignant tumours. There is some evidence that the other trihalomethanes are also carcinogenic. Risk assessment using data from the rodent studies suggests that low doses of chloroform may produce some incidence of cancer in man. Based on a very conservative statistical model, at a maximum acceptable concentration of 0.35 mg/L, the health hazard to man posed by the presence of trihalomethanes is considered negligible. Trihalomethane levels in surveyed public water supplies are generally well below this concentration.

Uranium

Uranium is normally present in biological systems and aqueous media as the uranyl ion (UO_2^{+2}). Ingestion of large quantities of uranyl ion may result in damage to the kidneys. The uranyl ion may also be responsible for objectionable taste and colour in water, but the concentrations at which this happens are much higher than the concentrations which may cause kidney damage.

The existing data are insufficient to permit establishment of a maximum acceptable concentration for uranium in drinking water.

The available information does suggest that water containing 0.02 mg/L uranium would not pose a health risk. Therefore an interim limit of 0.02 mg/L is being recommended. This value is considered to be ultra-conservative and should be used with discretion and if exceeded should signal the need for more sampling to establish possible fluctuations of uranium concentrations and radionuclide activity in the drinking water.

Zinc

The maximum desirable concentration of zinc in drinking water, 5.0 mg/L has been set on the basis of aesthetic considerations. Water containing zinc at levels greater than 5.0 mg/L tends to be opalescent, develops a greasy film when boiled, and has an undesirable astringent taste. The concentration of zinc in tap water may be considerably higher than in the corresponding source water due to the use of zinc in galvanized pipes. Corrosion control will therefore often minimize the introduction of zinc into drinking water.

RADIOLOGICAL CHARACTERISTICS

Man's exposure to radiation results from external sources such as cosmic and terrestrial radiation and internal sources such as radionuclides taken into the body with food, water, inhaled air and particulate matter. With respect to internal sources, the

important factors to be considered from the health viewpoint are the radiation doses delivered to the organs and tissues of the body resulting from intakes of radionuclides. The radionuclides currently of greatest interest from a health viewpoint are tritium, strontium-90, iodine-131, cesium-137, and radium-226. The guidelines for these radionuclides are set out in Table 2-6 .

The guidelines for the radiological characteristics of water are based on dose-response relationships as recommended by the International Commission on Radiological Protection (ICRP). Maximum acceptable concentrations in drinking water have been derived which correspond to one per cent of the ICRP recommended annual occupational dose equivalent limits for continuous exposure. Target concentrations have been derived which correspond to one tenth the maximum acceptable concentration. An average daily intake of 2 litres of drinking water is assumed.

TABLE 2-6 Guidelines for Radionuclides

Radionuclide	Maximum Acceptable Concentration* Becquerels/Litre	Target Concentration** Becquerels/Litre
Cesium - 137	50	5.0
Iodine - 131	10	1.0
Radium - 226	1	0.1
Strontium-90	10	1.0
Tritium	40 000	4 000.0

The above limits refer to the sum of all forms present.

* Radionuclide concentrations exceeding the maximum acceptable concentrations may be tolerated provided that the duration of the increase is short and that the annual average concentrations remain below this level and meet the restriction of multiple radionuclides.

** The target concentration is intended to be a guideline for life-long continuous consumption. Radionuclide concentrations exceeding this level on a continuous basis are acceptable provided the situation is reviewed by the health authorities, taking into account factors such as magnitude and duration of population exposure.

SUBJECT:

WATER TREATMENT OPERATIONS

TOPIC: 3

Ground Water Supplies

OBJECTIVES:

The trainee will have:

1. An appreciation of the occurrence of ground-water, some of the properties of aquifers, as they relate to municipal well-water supplies.
2. An understanding of some of the types and construction details of municipal well-water supplies.
3. A knowledge of the role of the plant operator in the collection and presentation of water level data and in the assessment of aquifer response to withdrawal and to seasonal variations.
4. An understanding of the importance of the chemistry of ground water and the effect that long-term pumpage can have upon well-water quality.
5. A knowledge of the purpose and types of well testing programs, as they relate to the chemical, bacterial, and physical factors which affect well pumpage.
6. An awareness of the mechanical and chemical rehabilitation methods of well-water supplies.
7. A familiarity with some of the common design criteria for well pumphouses.

GROUND WATER SUPPLIES

INTRODUCTION

Good management in a well or well field is essential. Consideration should be given to the management of a ground water supply once it has been developed and the well(s) put into operation. The management of the well-water supply system must be focussed on the aquifer or water-bearing formation and the well. Only by effectively monitoring the response of each to pumping can good management be practised. Too often the philosophy exists "out of sight out of mind".

In many communities a well developed and maintained supply of ground water can be an inexpensive source of water which can generate revenue and provide stimulus for economic growth. The suitability and adequacy of a community's ground water supply can be the deciding factor on whether an industry will relocate or expand its operations. A poorly maintained well supply will result in progressively higher operating costs (i.e. hydro) and in higher water rates.

The most important factor that must be considered in any well water supply system is the aquifer (Figure 1). It is the limiting factor on the yield of a well or well field. It is important to know as much as possible on the aquifer size and shape, the chemistry of the ground water, the well yield and the hydraulic characteristics of the aquifer. Most large capacity wells today are constructed under the supervision of a Consulting Hydrogeologist. The Hydrogeologist prepares a report analyzing the results of the well construction and testing program. His report will usually contain an "as built" drawing of the well i.e. (Figure 6) and a graphical presentation of the water level data collected during test pumping, i.e. (Figure 3). A perennial yield will be assigned to the well based upon an analysis of the water level data and on other hydrogeologic data available to the

Hydrogeologist. As operators you should have a copy of his report on file at the plant for reference. Although it cannot be expected that you will fully understand the hydrologic system in detail, you should have a basic understanding of some of the terms and principles used in hydrogeology and in the water well industry and of some of the problems that you may experience during the operation of your well and on what corrective measures you can take to overcome these problems.

DEFINITION OF AN AQUIFER AND OF COMMON TERMS
RELATING TO PUMPING EFFECTS ON AQUIFERS

Aquifer

A water saturated geologic unit that will yield water to wells at sufficient rates so that the well can serve as a practical source of water, (Figure 1). Aquifers may be unconfined and semi-confined.

Unconfined Aquifer
(Water Table)

An unconfined aquifer is a permeable bed only partly filled with water overlying a relatively impervious layer. Its upper boundary is formed by a free water table or phreatic level under atmospheric pressure. Water in a well penetrating an unconfined aquifer does not rise above the phreatic level.

Confined Aquifer
(Artesian)

A confined aquifer is a completely saturated aquifer whose upper and lower boundaries are impervious layers. Completely impervious layers rarely exist in nature and hence

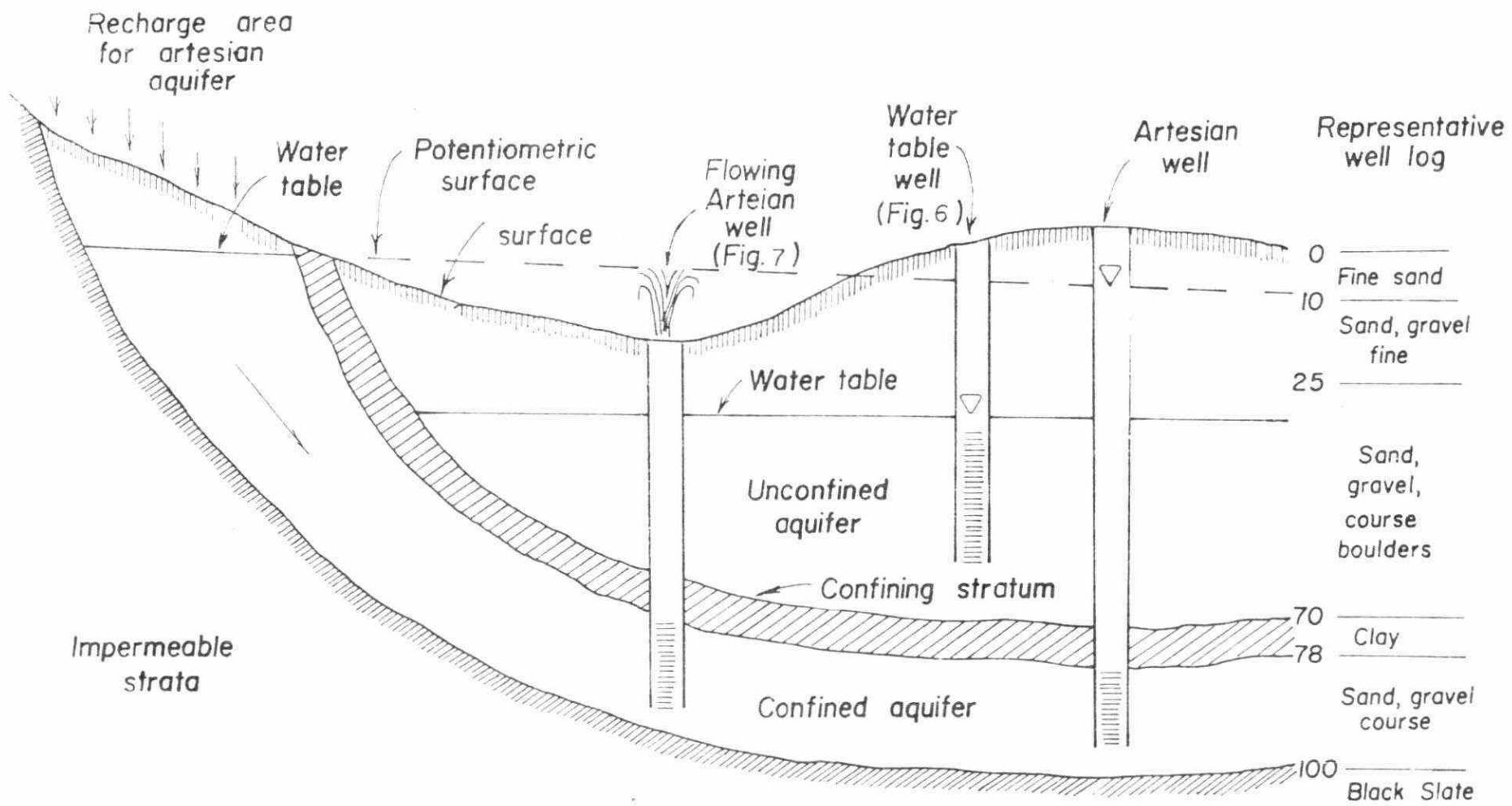


Figure 1

Diagrammatic representation of aquifer types

confined aquifers are less common than is often recognized. In confined aquifers the pressure of the ground water is greater than atmospheric pressure and the water level in wells stands above the top of the aquifer.

Semi-Confined Aquifer

A semi-confined or leaky aquifer is a completely saturated aquifer overlain by a semi-pervious layer and underlain by a layer that is impervious. A semi-pervious layer is defined as a formation which has a low though measureable permeability. Lowering of the potentiometric head in a leaky aquifer by pumping will generate a vertical flow of water from the semi-pervious layer into the pumped aquifer.

Static Water Level

Static water level is the level at which water stands in a well when no water is being taken from the aquifer by pumping. It is a measure of the depth from the ground surface or from a known measuring point to the water level in the well when the well is at rest. It may be above or below ground level.

Pumping Level

Is the level at which water stands in a well when pumping is in progress. It is a measure of the depth of the water level from ground surface or from a known measuring point during pumping.

Drawdown	Is a measure of the amount of lowering of the water level in the well when pumping is in progress. Drawdown is the measured difference between the static water level and the pumping level at any point in time.
Cone of Influence	When water is pumped from a well a depression in the water table or potentiometric surface is produced. This depression is called the cone of influence of a well. The cones of influence of two wells close together may overlap so that if the wells are pumped simultaneously they will compete with each other for available ground water. The effect is called well interference.
Specific Capacity	Is a measure of the number of gallons per minute pumped per foot of drawdown in a well at any point in time. Knowing the specific capacity of a well, the operator can estimate approximately the drawdown that will be produced at different pumping rates. For example, a well with a high well efficiency delivers 300 gpm with 15 ft. of drawdown. The specific capacity of that well would be $\frac{300}{15}$ or 20 gpm/ft. At 200 gpm the drawdown would be $\frac{200}{20}$ or 10 ft.

Calculating the drawdown for rates greater than those actually experienced is possible when wells are completed in overburden aquifers but not in rock aquifer.

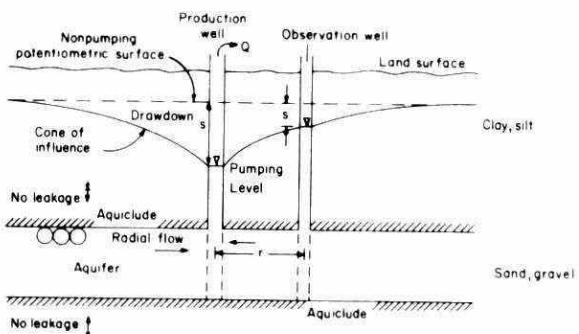
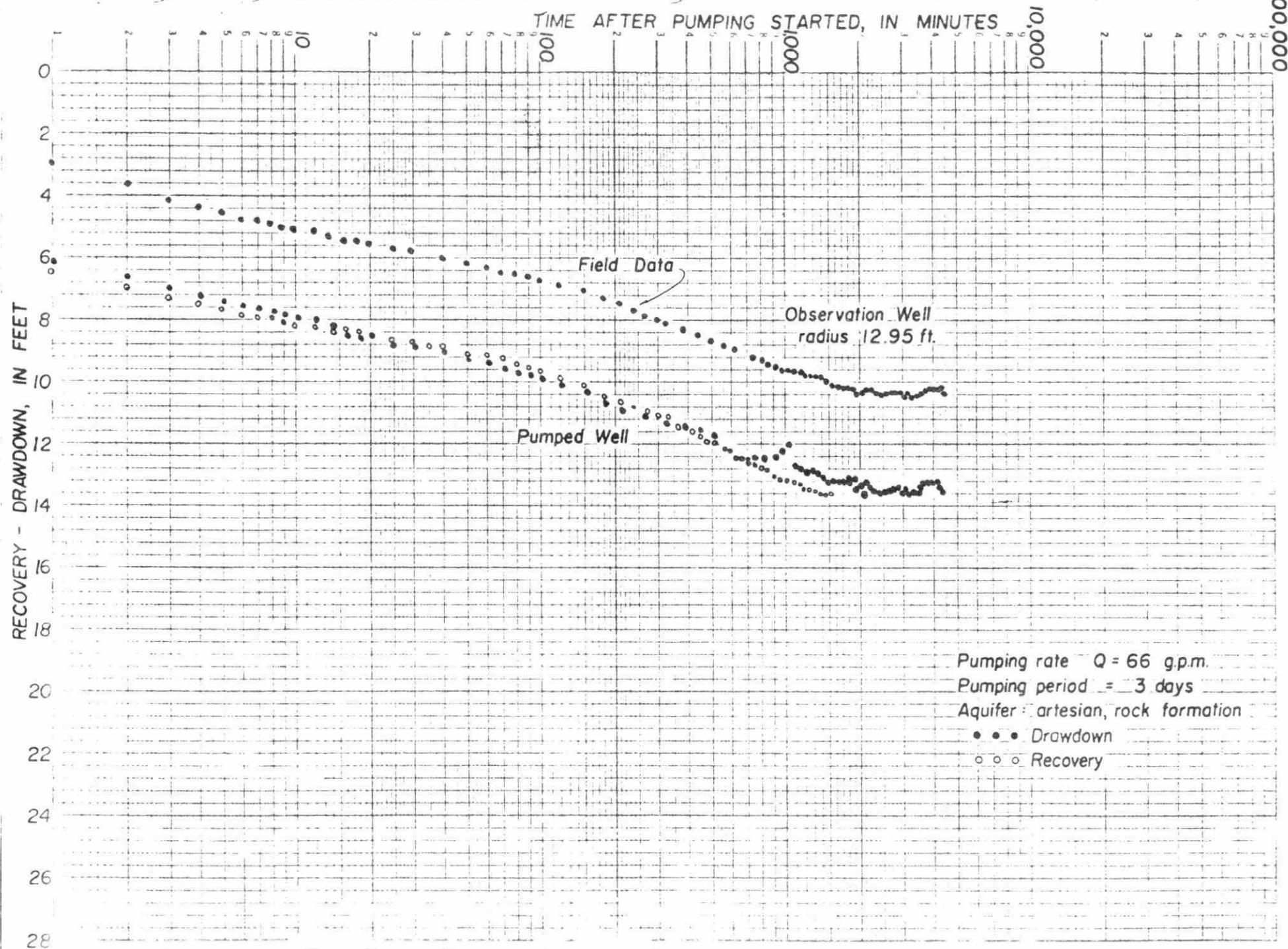


Fig. 2 Pumping artesian aquifer with fully penetrating wells

WELL DESIGN

It is important to be familiar with the construction details of your well(s). It would be useful if the technical information on the well was available at the pumphouse for ready use. The information that should be included are the diameters and depth of all well casing installed, the well driller's geological log, and how the well was finished. If a well screen was used, the Manufacturer, nature of material, slot size of the well screen, and depth setting should be listed. Sources for this information are the Hydrologist's Report or the Drillers Water Well Record. A copy of the latter can usually be obtained from the Technical Support Section of the local Ministry of Environment Regional Office.



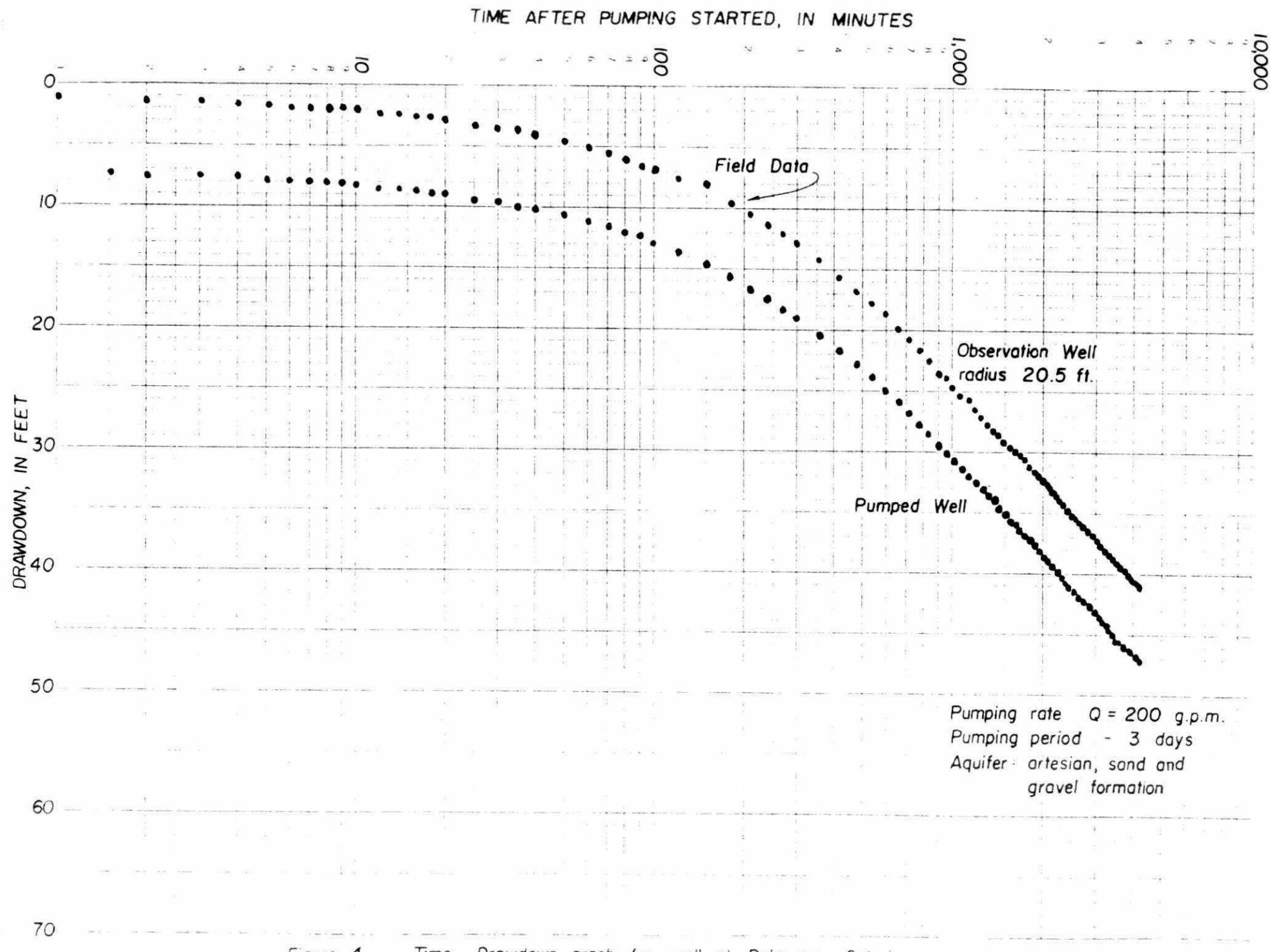


Figure 4 Time - Drawdown graph for well at Delaware, Ontario

Ground water supplies can be developed from rock and overburden aquifers each of which requires different design criteria.

In a consolidated rock aquifer (Figure 5) the intake portion of the well comprises openings such as fissures, joints, fractures, etc., in the open well bore. The yield and depth of a well in rock varies with the number, size and continuity of the openings in the rock aquifer.

In an unconsolidated aquifer the most important element of a well is the well screen which allows access to the aquifer and ensures that sand-free water is produced. In the selection of a well screen, the physical and hydraulic properties of the aquifer are considered since they will influence the well's performance and efficiency. A properly selected well screen will allow water to enter the well at the design rate at velocities at or less than 0.1 ft/sec with a minimum of drawdown.

There are two types of screened wells, the artificially gravel packed (Figure 6) and the naturally-developed well (Figure 7). In a gravel-packed well the formation material immediately surrounding the well screen is removed and replaced by a more permeable artificially graded silica sand to form an envelope around the screen. In the naturally developed well up to 60% of the finer formation material surrounding the screen is removed by well development to create the permeable zone. In each case, there is a net increase in the effective diameter of the well.

COLLECTION OF WATER LEVEL DATA

The quantity of ground water stored in the aquifer and its response to pumping can be monitored by means of measuring water levels in observation wells or commonly by measuring water levels in the pumped well.

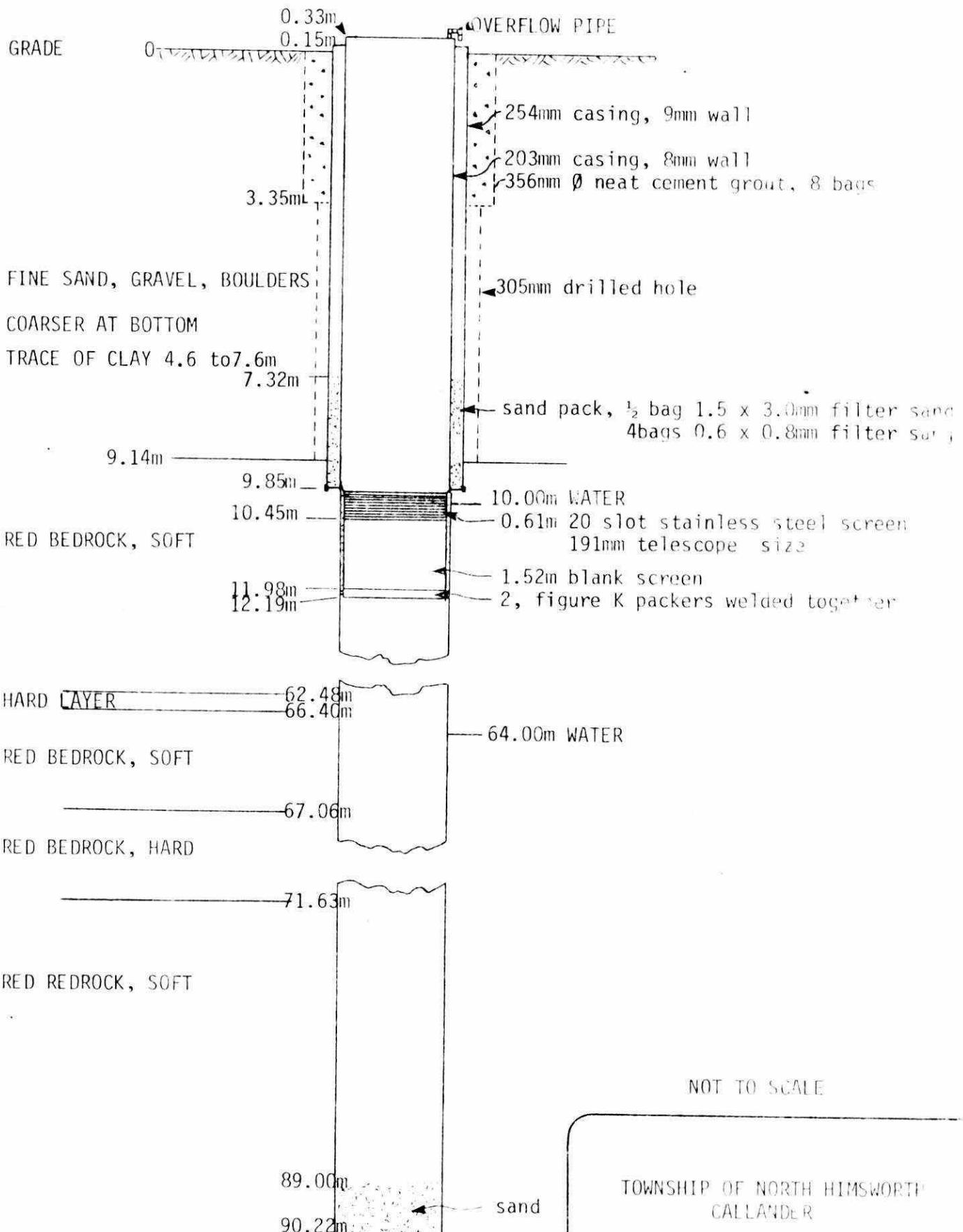


Figure 5 - As-Constructed drawing of well completed in rock but screening overburden, Callander

WELL MATERIAL

Outer Casing $4\frac{1}{2}$ " dia., $5\frac{7}{8}$ " Wall Thk. Matl. $\frac{1}{2}$ "
 Cemented from 5' to 20' " "
 Inner Casing $2\frac{1}{2}$ " dia., $3\frac{1}{2}$ " Wall Thk. Matl. $\frac{1}{2}$ "
 Screen Make $\frac{1}{2}$ " dia., Opening & Matl. $\frac{1}{2}$ "
 Plug: Type $\frac{1}{2}$ " dia., Matl. $\frac{1}{2}$ " Steel Other
 Gravel: Type $\frac{1}{2}$ " dia., Size 0.8 Quantity 200 $\frac{1}{4}$ "
 $100 \times \frac{1}{4}$ " 4500 lb

WELL TEST DATA

Preliminary Test Date: 11/09/17/14 by $\frac{1}{2}$ "
 Static Level: 39.90' " below M.P. Q-3'
 Pumping Rate IGM: 1500
 Pumping Duration: 72 hrs. 0 min
 Pumping Level at Test End: 34.50' "
 Performance Plots: dd-t Dwg. A75521
 dd-r Dwg. A75517

Final Test: Date _____ by _____
 Rated Well Capacity IGM _____
 Pumping Rate IGM _____ Static level _____
 Pumping level _____ " at _____ hrs. _____ min
 Pump pressure: _____ psi Main pressure _____
 Shut off: AGH _____ psi W.L. _____
 Clear Well Depth from B.P. _____ " Air Line _____

PUMP & MOTOR DATA

Pump Make _____ Rating _____ IGM (a) _____
 Head: Type _____ S.N. _____
 Column: _____ " X _____ " X _____ " : Shaft Mth. _____
 Bowl: _____ Stage _____ Curve _____
 Suction: _____ " dia. _____ " L. _____
 Special: Zinc Sleeves _____ Taped Oil Line _____
 Other _____
 Motor Make: _____ Frame: _____ S.N. _____
 _____ HP, _____ ph, _____ hz, _____ rpm
 Bearing No. Upper _____
 Lower _____

Special Equipment

Not equipped

WELL REVISIONS AND REHABILITATION

DATE	WORK DONE	BY

International Water Supply Limited

SASKATOON - BARRIE - MONTREAL

CLIENT: ONE. IGNACE (1-2-18-015-2)

WELL NO. 1

DRILLED BY J. Ignace	DATE 11/09/14	DRAWN J.W.
INSTALLED BY	DATE	DATE J.W.

Figure 6 - As-Constructed drawing of gravel-packed well in water table aquifer, Ignace

DRILLERS LOG

0

CLAY and STONES

28.0'

SANDY CLAY

and

GRAVEL

550'

static water level + 16.18 ft.

pumping rate (g.p.m.)	water level (ft.)
100	+ 13.65
200	+ 12.24
300	+ 9.86

SANDY GRAVEL

105.0'
Bottom of Hole

WELL CONSTRUCTION DETAILS

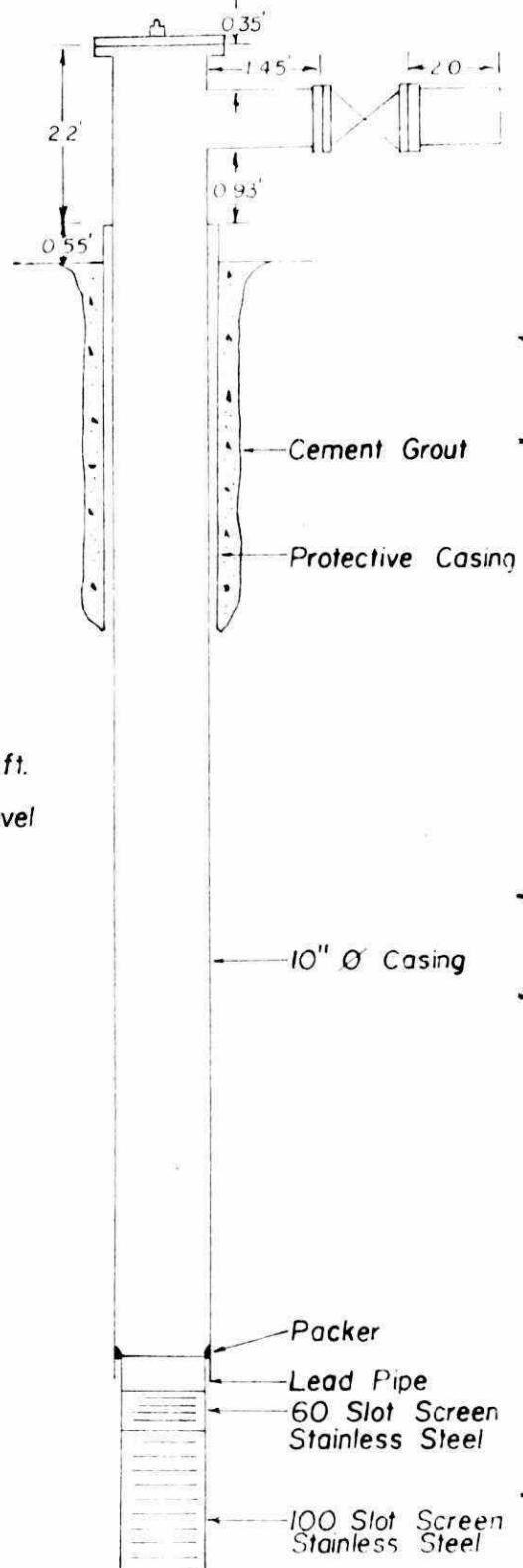


Fig. 7 A - Constructed drawing of flowing artesian naturally - developed well, Millbrook

The static water level and pumping levels in each well should be measured daily. The most commonly used methods are: air line, wetted tape or depth gauge. Most wells are equipped with an air line (Figure 8).

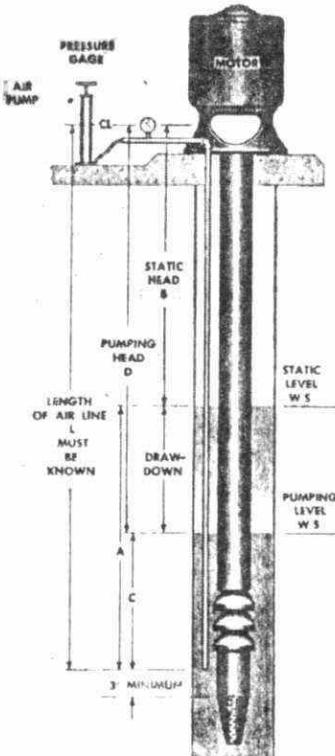
Example: Assume a length (L) of air line (telltale) of 150 feet. Assume that the pressure gauge reading (P1) before starting the pump is 25 psi. Then pressure converted to feet (A) is $25 \times 2.31 = 57.7$ feet. The static water level (B) equals $L - A = 150 - 57.7 = 92.3$ feet. Assume that the gauge reading P2) during pumping is 18 psi. Convert to feet (C) this is $18 \times 2.31 = 41.6$ feet. Then the pumping level (D) = $L - C = 150 - 41.6 = 108.4$ feet.

The drawdown is determined by any of the following methods:

- 1) $D - B = 108.4 - 92.3 = 16.1$ feet
- 2) $A - C = 57.7 - 41.6 = 16.1$ feet
- 3) $P1 - P2 = 25 - 18 = 7$ psi;
 $7 \times 2.31 = 16.1$ feet

Figure 8

Use of air line
to find depth
of water



PRESENTATION OF WATER LEVEL DATA (Figures 9 & 10)

Accurate records of pump operation and well performance are invaluable for good operation. Such records will usually provide the necessary information to trace trouble to the pump or the well. Seasonal patterns become evident and well performance can be predicted. Records assure proper rotation in the use of wells.

Long term records show the general trend of well yield and indicate when specific maintenance is needed. The types of well records used by the Ministry is Form MOE 0641(H-K)1/79.

The form indicates which pumps and wells are in use and for what periods of time. This Form can be used to determine schedules to equalize the use of wells and pumping equipment by alternating periods of service and to detect changes in well characteristics and conditions. The Form indicates water level information, pumpage, duration of pumpage, etc.

Water level data are obtained principally from measurements taken of wells.

The record of water levels in a well taken over a period of time and plotted on a graph is a well hydrograph (Figures 9 and 10).

Most water level changes result from:

- 1) Changes in the amount of water in storage
- 2) Natural discharge and recharge
- 3) Reduced discharge and recharge
- 4) Changes in atmospheric pressure
- 5) Disturbances within the well

The following are a few examples that show interpretations that can be made when properly maintained records are available for review:

- a) A declining static water level may indicate a gradual lowering of the water table or the piezometric surface because of interference by other wells, mining of the aquifer, or the natural changes in storage referred to in the above.
- b) An increase in the drawdown in a well may indicate declining static water levels, interference, clogging, scaling or corroding of the well screen, plugging of the gravel pack, etc.
- c) An increase in the drawdown in a well when the static water level is unchanged is caused by increased resistance to flow through the well bore, well screen or rock aquifers resulting from chemical or physical clogging, scaling, or corroding of the well screen or well bore.

WELL FIELD MANAGEMENT PROGRAM QUESTIONNAIRE

Once a well is put into service it cannot be forgotten because many of the factors effecting its capacity will change with time. If an operator cannot answer the following questions about the well field, money may be lost. More importantly, there is the risk of a crisis situation occurring.

- 1) What has been the general trend of ground water levels within the well field over the past 5 to 10 years?
- 2) What is the non-pumping level in each production well?
- 3) What is the pumping level in each production well?

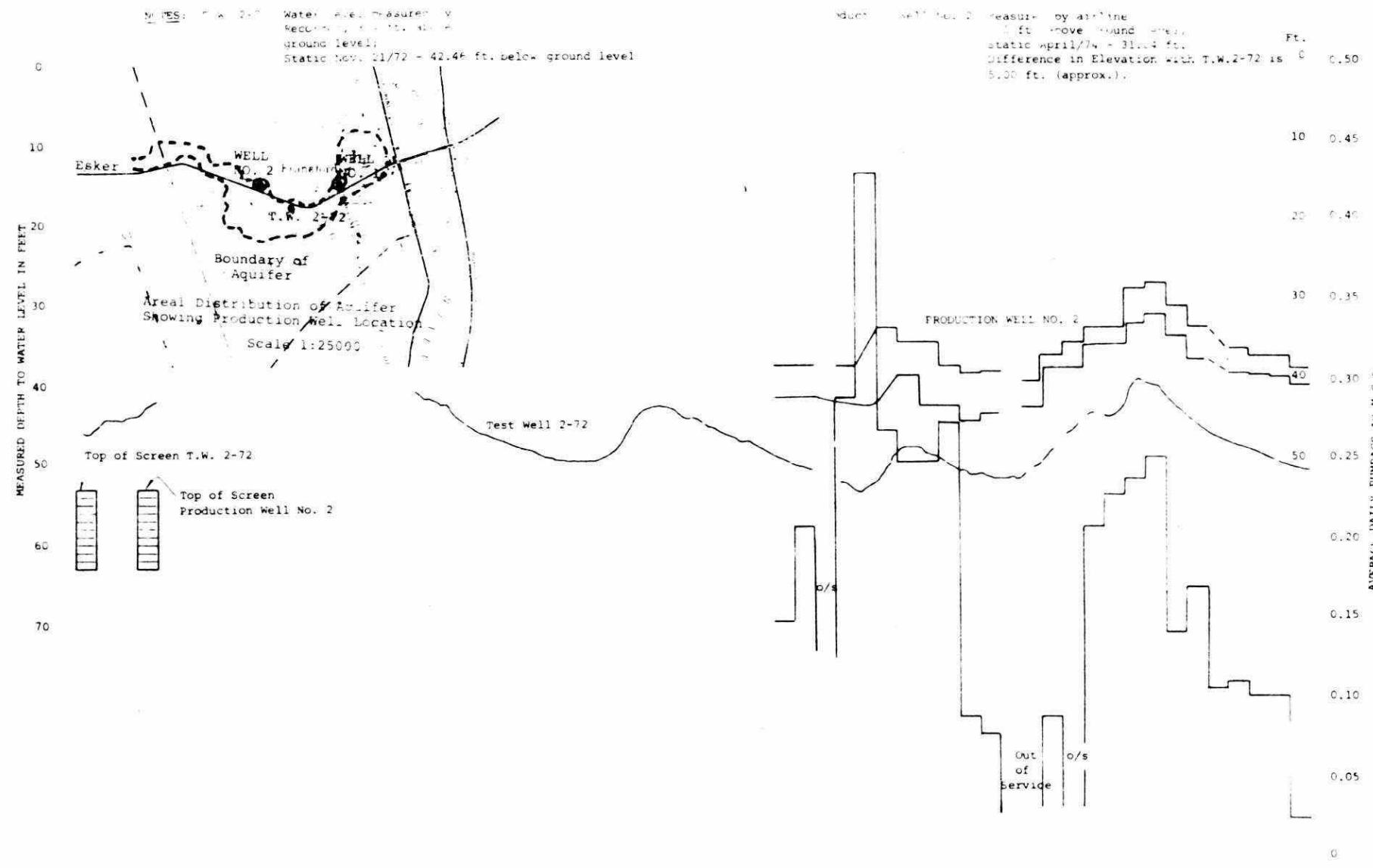


Figure 9 - Hydrograph of selected wells and outline of aquifer under water table conditions, Village of Frankford

NOTES: T.W. 2-72: Water level measured by
Recorder, 3.4 ft. above
ground level;
Static Nov. 21, 72 - 42.46 ft. below ground level

Product on Well No. 1: Measured by airline
1-2 ft. above ground level;
Static Aug./68 - 8.5 ft.
below ground level

Ft.
0 0.50

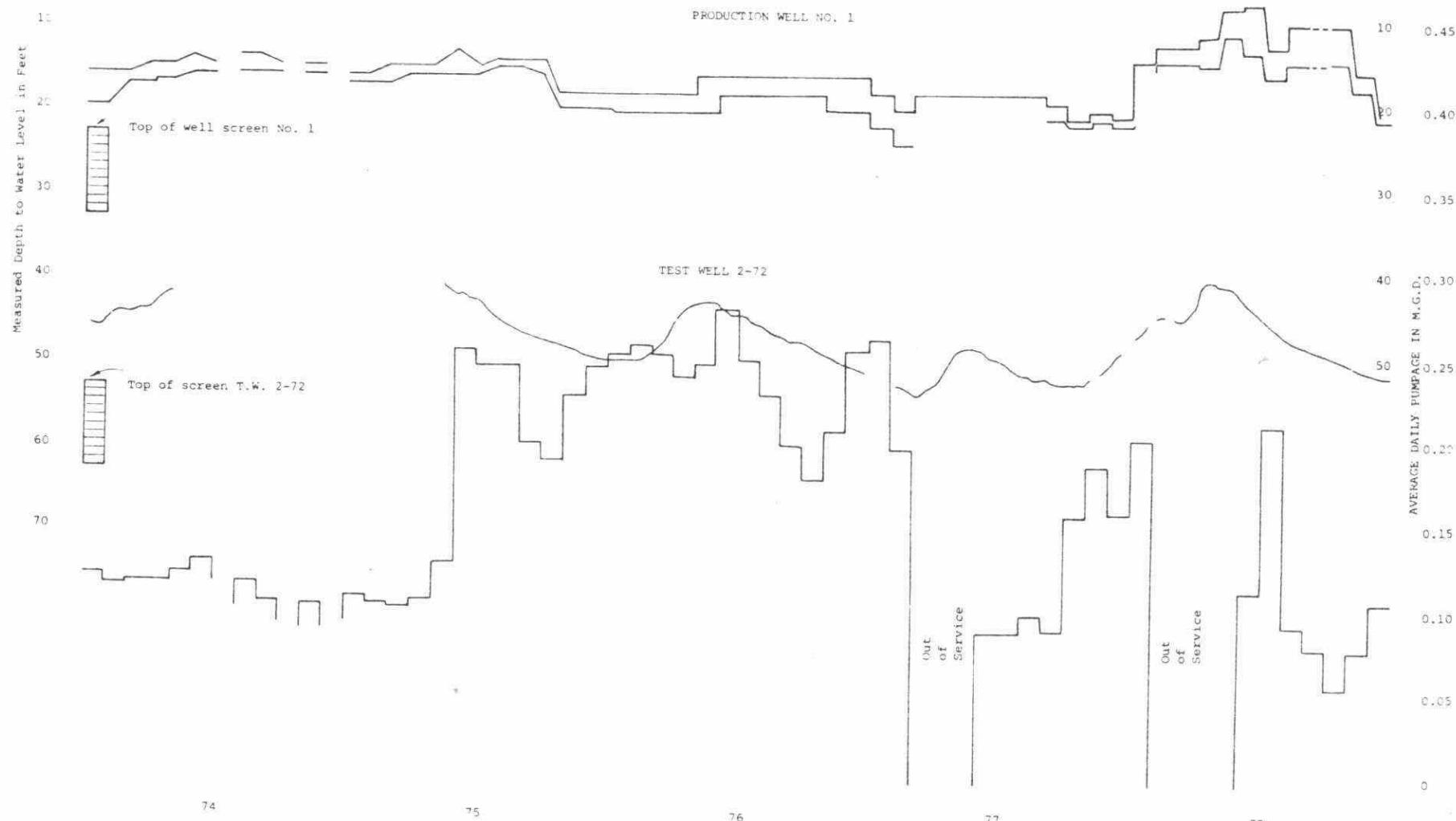


FIGURE 1 - Hydrograph of Village of Frankford Production Well No. 1 and Test Well No. 2-72 ($R = 960$ ft.) showing the depths of the water table and the average daily well pumping.

Figure 10 - Hydrograph of selected wells, Village of Frankford

- 4) What is the normal pumping rate for each well and how many hours per day does it operate?
- 5) What is the "critical" pumping level in each production well?
- 6) Where are the pump intakes for each well?
- 7) Where are the pump-rating curves for each pump?
- 8) What is the safe "perennial yield" of each well?
- 9) What is the present efficiency of each well?
- 10) When was the last time each well was rehabilitated and what is the program rehabilitation schedule?
- 11) What was the percentage improvement of well efficiency after rehabilitation?
- 12) How much drawdown is recorded in each well as the result of interference created by other production wells?
- 13) What is the total capacity of the existing well field in its present condition?
- 14) What is the potential capacity that can be developed at a present well field site?

Reference:

Simpson, C.L. "Well Field Management", Journal American Water Works Association, Vol. 70, No. 3, p.p. 151-152, (1978), New York.

PUMP OPERATION

From daily and monthly records the operator can determine whether the perennial yield or rate of yield of the well is being exceeded. To prolong the life of a well and the aquifer the perennial yield should not be exceeded. In a screened well for example, excessive pumping rates may cause

sand and silt to move in and around the well screen, thus clogging the screen and filling voids in gravel packed wells, thus reducing yield.

WELL WATER QUALITY

An operator should be concerned with the chemical and physical properties of well water pumped from the well he operates. He should collect raw water samples at least once a year for routine chemical analysis or more frequently if a water quality problem is known to exist in the area or the aquifer. The following parameters should be included in any routine analyses conducted. Nitrate, Na, SO_4 , Fe, Cl, pH, Hardness, Alk, Mn, Total Dissolved Solids. Figure 11 is a partial list of the results of the chemical analysis of well water samples collected at shutdown during the aquifer test of several different municipal wells completed in various aquifers. The results indicate the varied quality of well water obtained from the different aquifers and the different chemical treatment problems that can occur.

Two prime reasons for concern over the monitoring of well water quality are:

- (i) The possibility of inducing into the well by either vertical or lateral migration contaminated ground water, or ground water of a poorer water quality (Figure 12 and 13) and,
- ii) The possibility that during routine well operation in the right hydrochemical environment, corrosion or incrustation of the well screen or well casing may occur.

Corrosion is characterized by the deterioration and destruction of well screens, casing and pumps.

Incrustation is characterized by an accumulation of minerals, such as iron and carbonate on or near the well screen thereby inhibiting the flow of groundwater through the screen.

Corrosion and incrustation can be controlled but not prevented. If it is anticipated that the groundwater is corrosive, measures can be taken to reduce its effect, such as increasing the well casing and pump column wall thickness and by using corrosive-resistant metals in the well screen and various parts of the pump.

Where incrustation may be possible there are two practices which can slow its rate. The well screen entrance velocity should be kept as low as possible. This can be accomplished by various methods such as increasing the well screen open area, by increasing the well diameter to the maximum possible, by proper well development to ensure an efficient well and by reducing the rate of pumping and by operating the well longer to obtain the required quantity of water. Rehabilitation, the last resort, should be considered long before the problem becomes aggravated.

WELL EFFICIENCY

Well production capacity may decrease with pumping time due to slow plugging of the well screen and/or gravel pack.

Periodic well maintenance may be necessary if the rate of pumping from a well is to be maintained.

Wells should be rehabilitated before plugging becomes excessive, that is before the operating efficiency of a well has been reduced by 20%.



The logo for the Ontario Ministry of the Environment. It features a circular emblem on the left containing a stylized three-leaf plant. To the right of the emblem, the text "Ontario" is written in a bold, sans-serif font, and below it, "Ministry of the Environment" is written in a smaller, regular sans-serif font.

TABLE

SUMMARY OF CHEMICAL ANALYSES OF WATER

All analyses except pH reported in mg/l unless otherwise indicated

CC&S
MICROGRAPH

GC -56

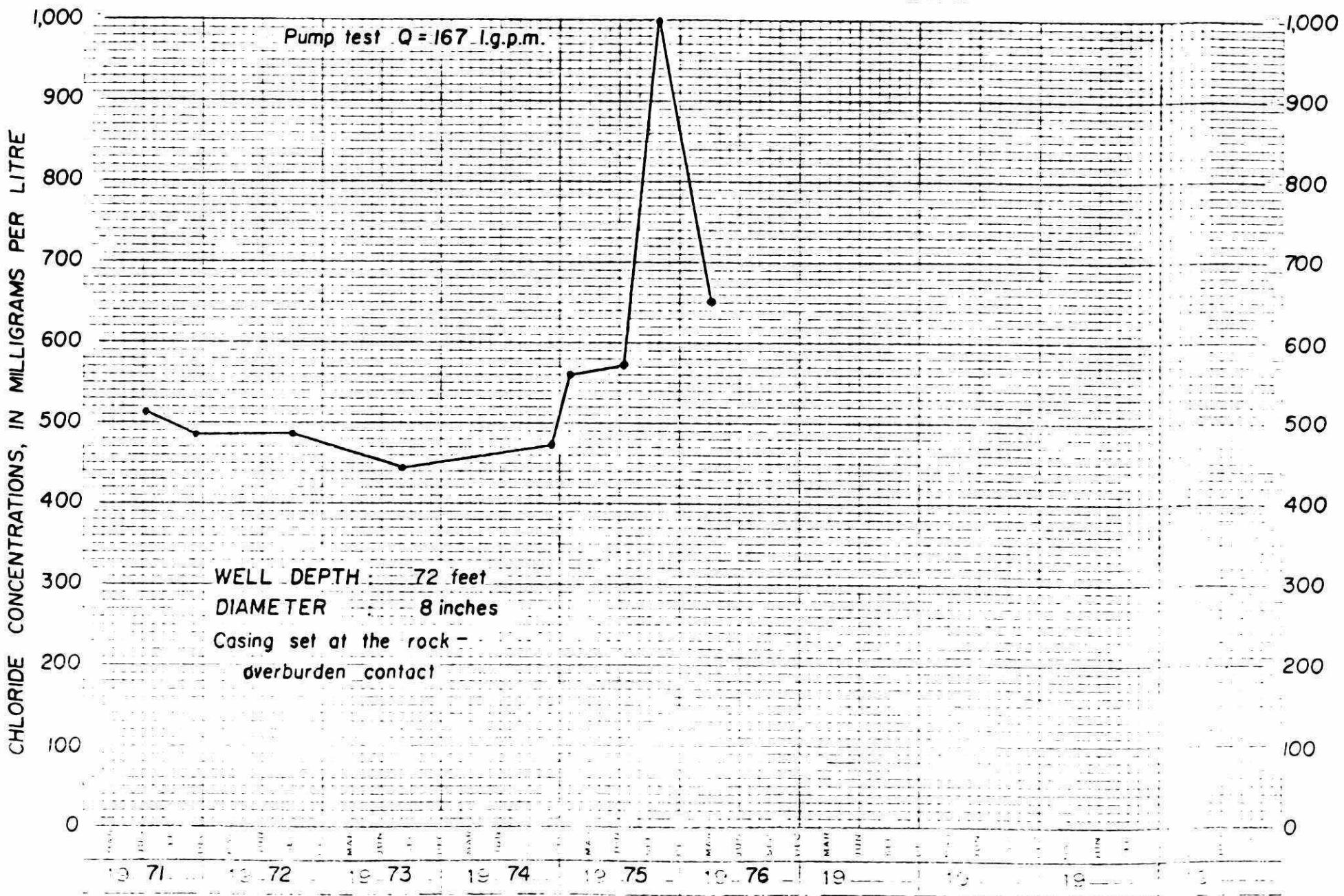
TEN YEARS BY MONTHS X 100 DIVISIONS
MADE IN CANADA

Figure 12 Chloride Concentration of water from municipal well Township of Cambridge

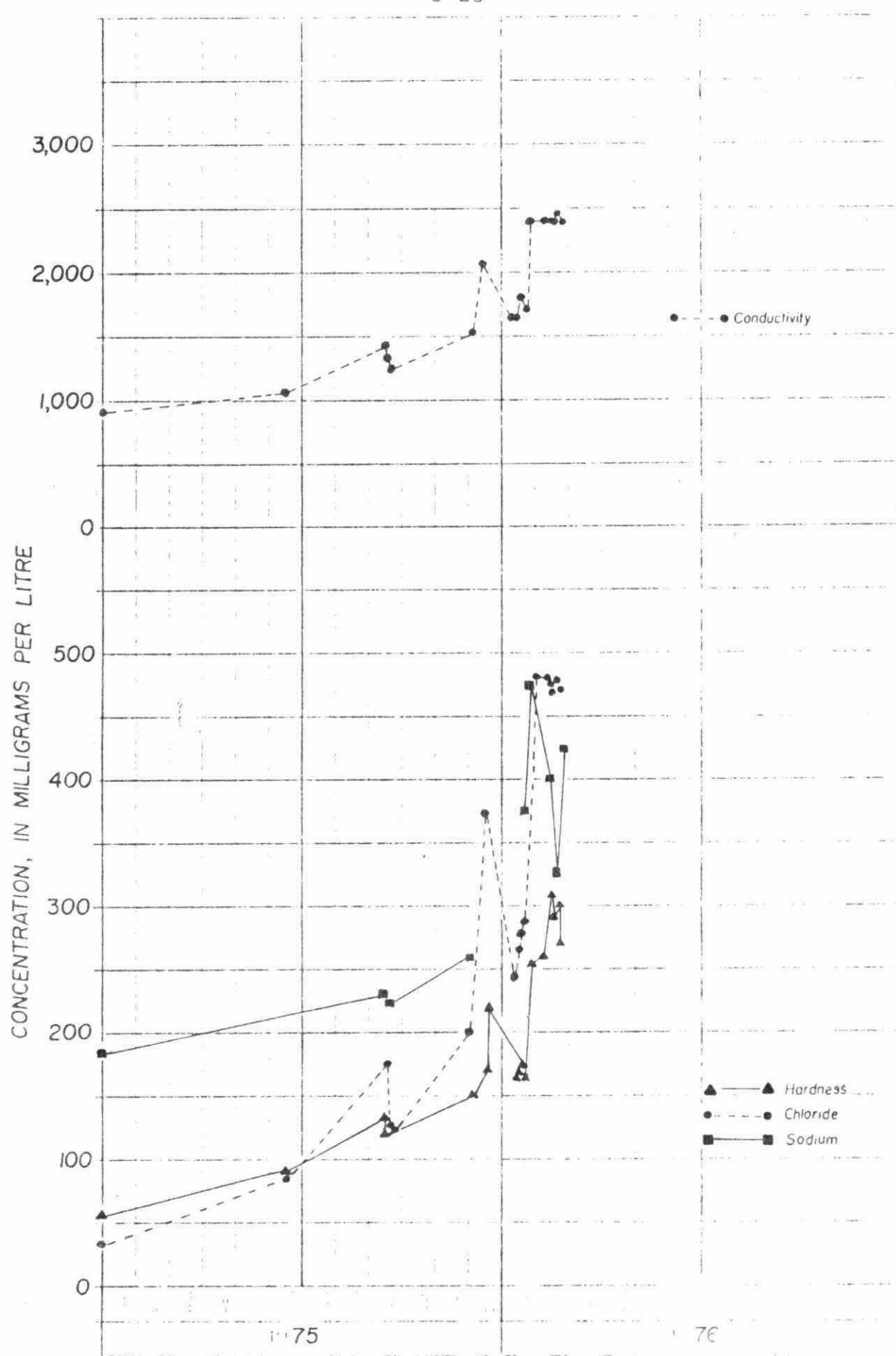


Figure 13 Hydrochemical changes in water from municipal well L'Original, Ontario

The drawdown in a pumping well can be divided in two components, the laminar formation loss and the turbulent or well loss.

The formation loss is controlled by the aquifer characteristics while the well loss is the result of turbulent or restricted flow in the well bore or in the aquifer close to the well bore.

Well losses may be caused by poor construction techniques, ineffective well development, or incrustations.

Pumping Tests

The performance of a well can be evaluated by conducting step-drawdown and drawdown-distance pumping tests.

In a step-drawdown pumping test the well is pumped continuously for three 1-hour intervals at progressively increasing pumping rates ending at the design rate (Figure 14).

The purpose of the step-drawdown test is to separate the drawdown into its components in order to define well efficiency as a basis for well acceptability. The general principle followed is a small well loss component indicates a properly designed and developed well. While there is some conflict, the basic principle to be followed is to compute the value of the well loss factor and compare it to the original construction test data and establish the extent of decline in the well's efficiency.

The drawdown-distance test is a comparison between the observed drawdown and the theoretical drawdown in a pumped well obtained by projecting the drawdown observed in two or

more piezometers (Figure 15). By comparing the construction data the percentage change in drawdown can be calculated.

An alternate method is to compare the specific capacity data on a well. Caution must be exercised with this method because reductions in saturated thickness can decrease the specific capacity of a well. Also the well drawdown must be measured at the same time interval in the pumping cycle because variations in the drawdown-time relationship of the pumped well can occur.

Plugging Processes

There are three processes involved in the plugging of well screens, mechanical, chemical and bacteriological.

Mechanical plugging is often related to the well construction technique and will show up early in the history of a well. It is the result of the movement of fines or drilling mud into the gravel pack and is the result of incomplete well development or overpumping.

Chemical plugging is usually the result of the precipitation of dissolved minerals brought on by a change in the chemical equilibria of the ground water and resulting in the encrustment of the well screen and/or gravel pack.

Bacterial plugging is the result of an increase in activity by iron and sulphate-reducing bacteria leading to accumulations of filamentous organisms which develop thread-like slime growth plugging the well screen, gravel pack or formation.

WELL REHABILITATION

Well rehabilitation methods which usually fall into two categories, mechanical and chemical, can return a well to its original efficiency.

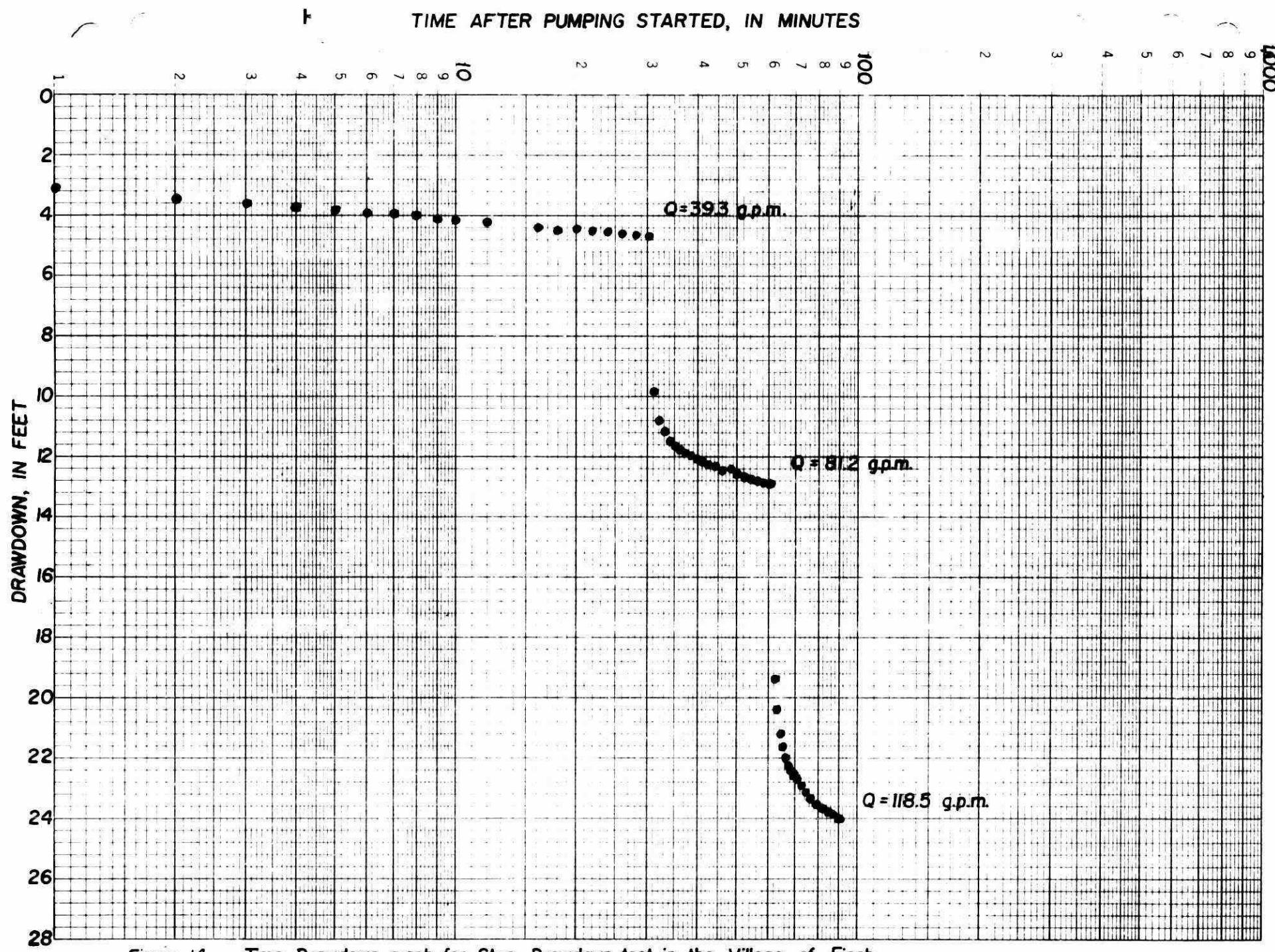


Figure 14 Time-Drawdown graph for Step-Drawdown test in the Village of Finch

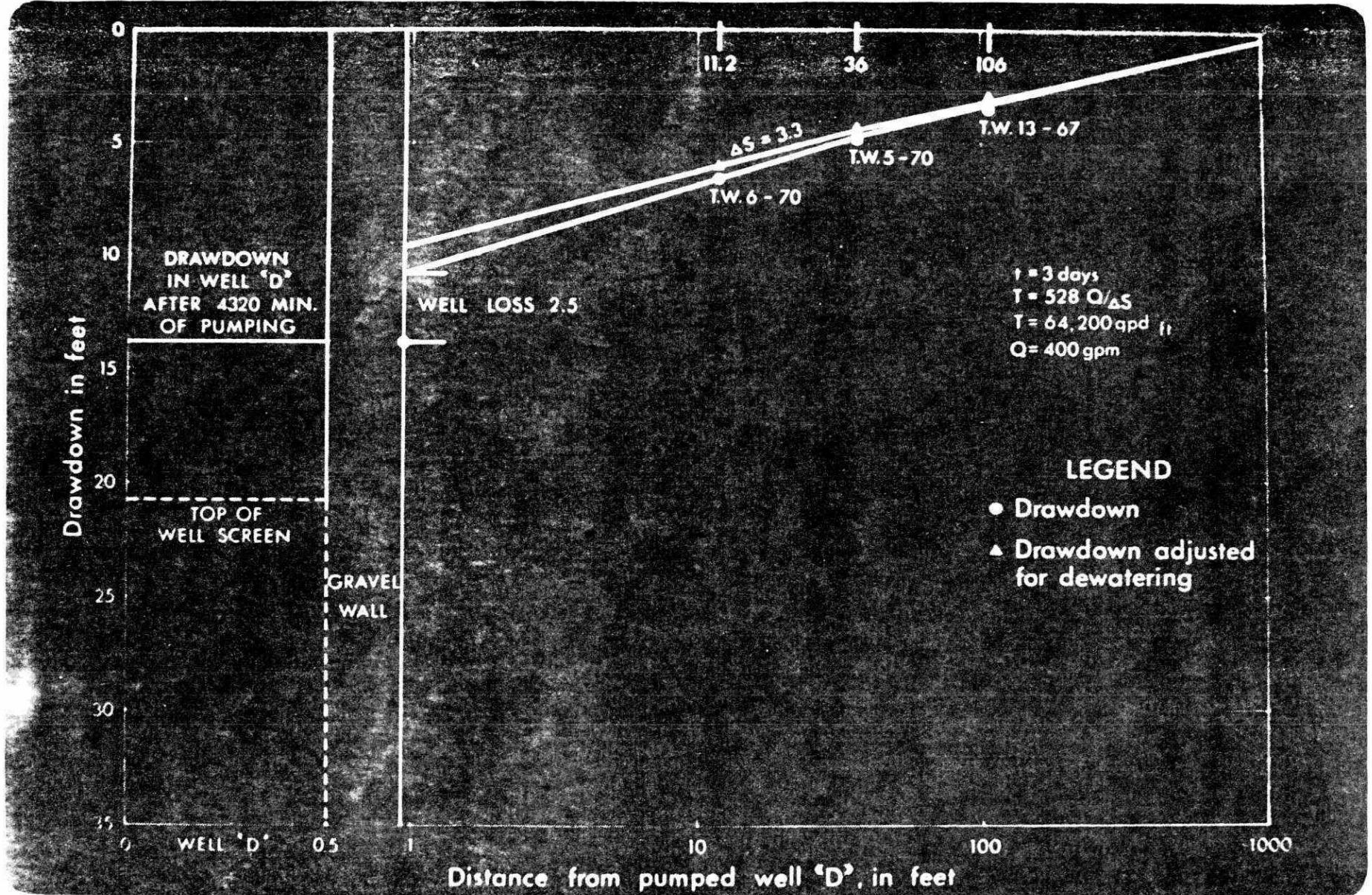


Figure 15 - Distance-drawdown graph for aquifer test in Blezard Valley, Sudbury

The mechanical methods involved are jetting, surging and backwashing while the chemical methods involve chlorination or acidization.

Commonly muriatic acid (hypochloric acid) is used to redissolve incrustants while chlorine is used to kill iron or sulphate-reducing bacteria. Polyp phosphates are used where clay, silts or drilling muds are determined to be the cause of reduced well efficiency.

To be successful a rehabilitation program should be carried out by trained and experienced personnel. The success of the operation will be governed by the following:

- 1) The well was initially satisfactorily constructed,
- 2) The well has not been severely damaged by pumping beyond its developed capacity,
- 3) The availability of historical water level data,
- 4) The availability of the results of chemical and bacterial analysis,
- 5) The treatment method is consistent with the cause of the reduced well efficiency.

GROUND WATER CHEMISTRY COMMENTS

General

For the purpose of this course, discussion of ground water chemistry will be limited to general observations which may be of value when chemical or bacteriological problems develop.

Changes in the natural chemical equilibria of ground water occur with a movement of water through well screen openings and up the well casing.

Well water from most deep wells contains no dissolved oxygen.

Iron bacteria infestation usually occurs through the introduction of surface contaminants during drilling operations or through leakage of surface water into a well.

A well penetrating several aquifers will allow ground water of possible different chemical qualities to mix in the well before and to move from one aquifer to another where different hydraulic heads exist.

Ground water mixing in the well bore when a well is at rest may produce well water of an unacceptable chemical and/or bacteriological quality which at pump start-up will be pumped into the system.

The impact of mixing may be reduced by: 1) lowering the rate of pumping and in turn the time of mixing, and 2) pumping the "mixed" well water to waste at start-up.

An effect of mixing may be iron precipitation and the slow plugging of water bearing fractures in some rock wells.

Dissolved Organic Carbon (DOC) is a fundamental measure of the pollution of the well water supply and may be used on a quantitative basis for determining the extent and limits of ground water degradation by organic compounds.

Inorganic and organic compounds can in concentrations of a few mg/l impart odour problems to well water, i.e. sulphate imparts a bitter taste to water. Activated carbon filters installed on domestic well water systems can adsorb taste and odour producing impurities.

Oxidizing agents such as chlorine and potassium permanganate will improve taste and odours.

Gas Related Problems in Well Water Supplies

The commonest dissolved gases in ground water include carbon dioxide, hydrogen, hydrogen sulphide, methane etc.

Reduced pressure in the aquifer caused by pumping lower the solubility of gas in ground water causing gas separation in either aquifer or well bore.

Gas separation may reduce the rate of ground water flow to a well increasing the drawdown or causing rapid fluctuation in the water level in the well.

Dissolved methane gas can be removed by aeration and by vigorous chlorination, prior to and during aeration. The chlorine will suppress nuisance organisms where their presence is indicated.

Cavitation is generally caused by entrained gas and improper pump design or use and will result in severe pitting and a characteristics spongy appearance in the metal of the pump impellers.

In cavitation the critical velocity of the fluid is reached and the fluid vaporizes forming pockets which collapse causing vibration in wall destruction.

Iron Bacteria

Significant infestations of iron bacteria in well water occur when the naturally occurring iron and manganese in ground water exceeds 0.2 mg/l.

Iron bacteria convert soluble iron and manganese salts into insoluble forms in the presence of air and derive energy from the reaction. Other bacterial types use organic materials in the water as a source of energy.

Infestations of iron bacteria may reduce well productivity by clogging the well screen.

Well water discoloured yellow, orange or red brown is most likely infested with iron bacteria.

A bacterial well water sample may be used to determine the presence of iron bacteria. The laboratory should be instructed to identify the iron bacteria present.

Chlorine concentrations of 1000 mg/l are commonly used in a well to kill iron bacteria. A source of chlorine is dry granular pelletized sodium hypochlorite.

The disinfectants used in the control of iron bacteria must penetrate the bacterial cell to kill the organism. The slime deposit of iron and manganese will retard a disinfectants penetration, so prolonged exposure times are necessary.

Iron bacteria are difficult to eradicate and regular preventative maintenance programs should be instituted.

Sulphate Reducing Bacteria

Hydrogen sulphide (H₂S) is recognized by its obnoxious rotten egg odour that can be detected in concentrations as low as 0.1 mg/l.

Hydrogen sulphide is less soluble in hot water than cold water so it is more readily detectable when using the hot water faucet.

The major source of hydrogen sulphide in ground water is anaerobic (oxygen deficient) sulphate reductions.

Sulphate reducing bacteria thrive in ground water under anaerobic conditions by reducing sulphate to sulphide which combines with the hydrogen in water to form hydrogen sulphide and elementary sulphur.

The hydrogen sulphide is corrosive and will attack steel casing and precipitate as iron sulphide while the sulphur is used by other bacteria.

Extremely low H₂S concentrations can be removed with an activated carbon filter by the process of adsorption or by oxidation with an agent such as chlorine.

Elevated H₂S concentrations in excess of 1.0 mg/l are generally treated by aeration to a level where the sulphide residual is less than 0.3 mg/l whereupon it is treated chemically with an oxidizing agent and filtered.

Pathogenic Bacteria

The common sources of pathogenic bacteria in the ground water regime are poorly located animal feed lots cesspools, septic tanks, landfill sites, etc.

The travel distance of pathogenic bacteria in ground water is limited to a few metres.

Well water bacterial quality is unsatisfactory when faecal coliform organisms are present and/or coliform bacteria are present in densities of 5 or more organisms per 100 ml.

A well water supply may be sterilized by rising the chlorine concentration in the well to 250 mg/l and allowing a contact time of 12 hours.

Incrustation

Treatment with muriatic acid (hypochloric acid) is the most common method redeveloping wells plugged by chemical precipitation.

Muriatic acid is dangerous to contact, and gives off toxic fumes.

Fulfamic acid in pellet form (UOP Johnson's Nu-well) works well on carbonated incrustation but is less effective on iron oxide although sodium chloride will increase its effectiveness. Sulfamic acid is safer than muriatic acid to handle.

COMMON DESIGN CRITERIA FOR WATER WELL PUMPHOUSES

- 1) The elevation of the top of the well casing should be above the existing ground surface, the normal flood level of any adjacent water body and at least 0.15 m above the floor level.
- 2) A pump pedestal, raised at least 0.15 m (6 inches) above the floor level, should be provided to support the full weight of the pump.
- 3) The well should be located within 1.3 m (4 feet) of an exterior wall of the pumphouse and centered under a hatchway in the roof, at least one metre (3 feet) square, to facilitate workover by a crane.
- 4) The piping layout in the pumphouse should include an in-line free discharge pipe to the outside of the building to permit future testing of the well. The end of the pipe should be equipped with a free discharge pipe orifice and monometer tap, calibrated to the design yield of the well.

- 5) A combination flow control and check valve, calibrated to the design yield of the well, should be positioned in advance of the free discharge pipe.
- 6) A digital flow meter should be positioned in advance of the free discharge pipe.
- 7) A sample cock should be installed in the piping to permit collection of raw well water samples.
- 8) Pressure gauges should be installed upstream and downstream of the flow controller.
- 9) A water-tight seal should be provided between the pump base or submersible discharge head and the pump pedestal or between the well casing and pump discharge column.
- 10) Auxiliary openings, at least 25 mm (1 inch) in diameter, should be provided in the pump base, submersible discharge head or well seal as required to provide vertical access to the inner well casing for an electric sounder and for the installation of accessory equipment.
- 11) The well should be equipped with an air vent. It should be vented to the outside of the building if explosive or toxic quantities of gas are present, and the auxiliary holes sealed.

- 12) The well is to be equipped with a water level measuring airline. The airline is to be clamped to the pump column, provided with a direct-reading pressure gauge in metres and calibrated to the water level in the well.

Note: At no time during the equipment and testing of the well pump is the rate of pumping to exceed the design yield of a well. Overpumping of a well can adversely affect the well's development and can result in decreased well efficiency and/or the pumping of sand from the well.

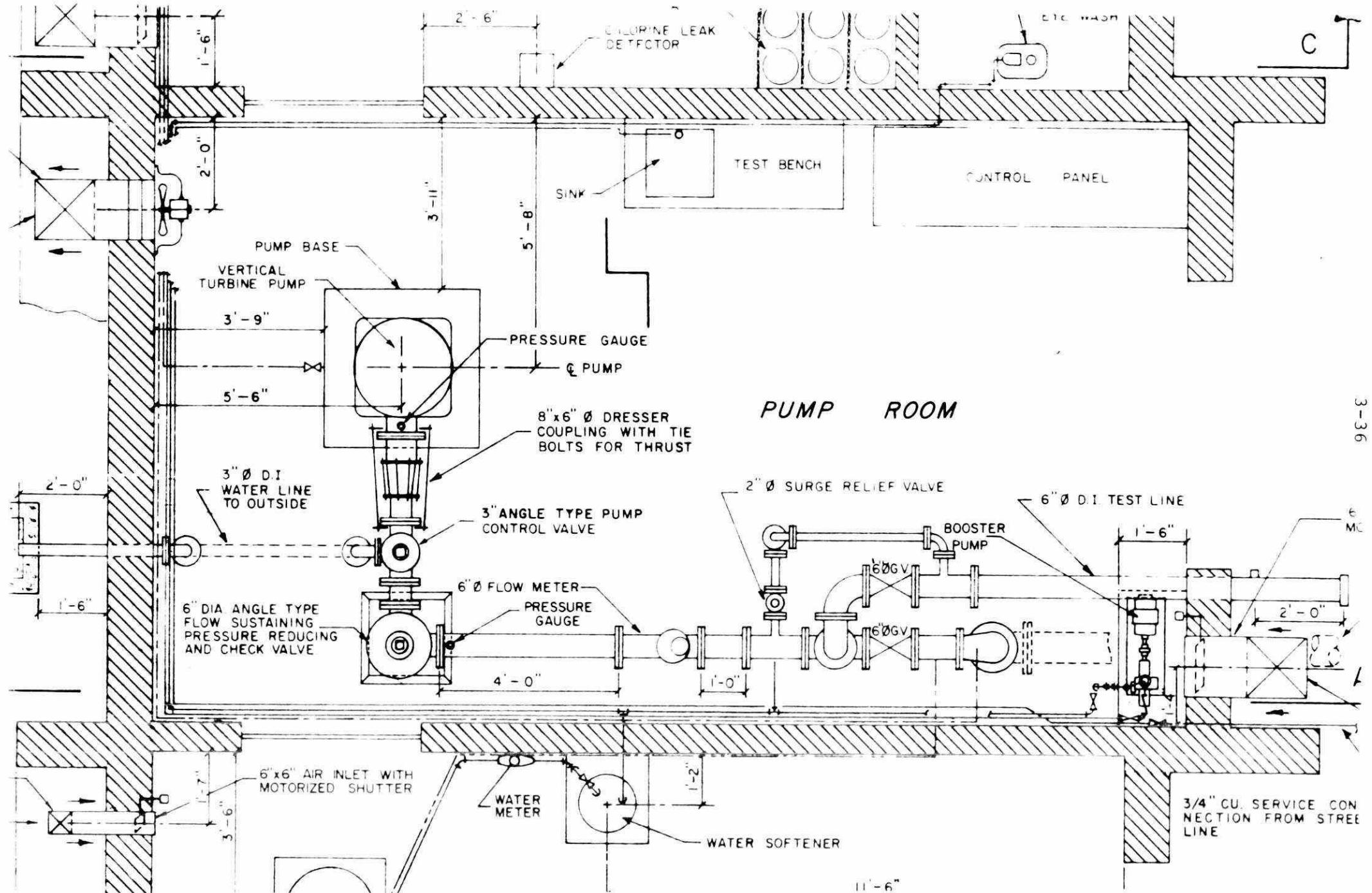


Figure 16: Well Water Pumphouse Equipment and Pumphouse Layout

1" Ø INSPECTION HOLE WITH
THREADED PLUG

1/2" Ø HOLE FOR 1/4" Ø
COPPER AIR LINE

1/2" Ø VENT PIPE SEE
NOTE NO 1

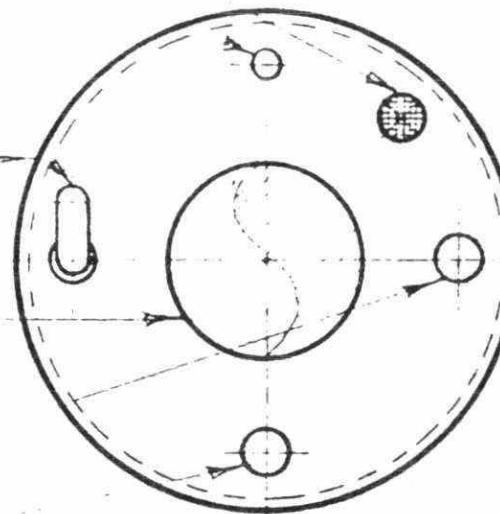
8" Ø SANITARY WELL SEAL

4" Ø PUMP DISCHARGE PIPE

1" Ø HOLE FOR PUMP CONTROL
ELECTRODE CABLES

1" Ø HOLE FOR PUMP WIRING

3-37



NOTES

1. VENT PIPE TO BE FROM THREADED
GALVANIZED STEEL WITH 180° RETURN
BEND, MOUNT 12" ABOVE SEAL.

2. SEAL TO BE MADE WATERTIGHT

3. FOR EXACT LAYOUT OF SANITARY
WELL SEAL, SEE MANUFACTURERS
SHOP DRAWING

SANITARY WELL SEAL DETAIL

SCALE - N.T.S.

Figure 17: Sanitary Well Seal Detail

SECTION B-B

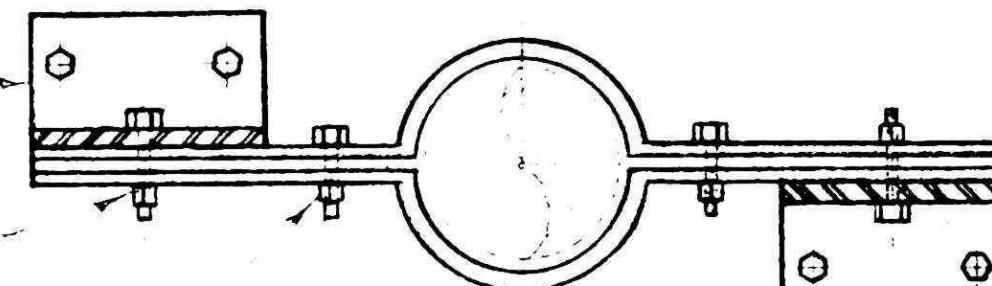
SCALE - $1/2" = 1'-0"$

8" 9"

8" x 4" x 3/8" GALVANIZED STEEL
ANGLE BOLT TO CONCRETE PIPE
WITH 1/2" Ø STAINLESS STEEL
ROTS (TYPICAL)

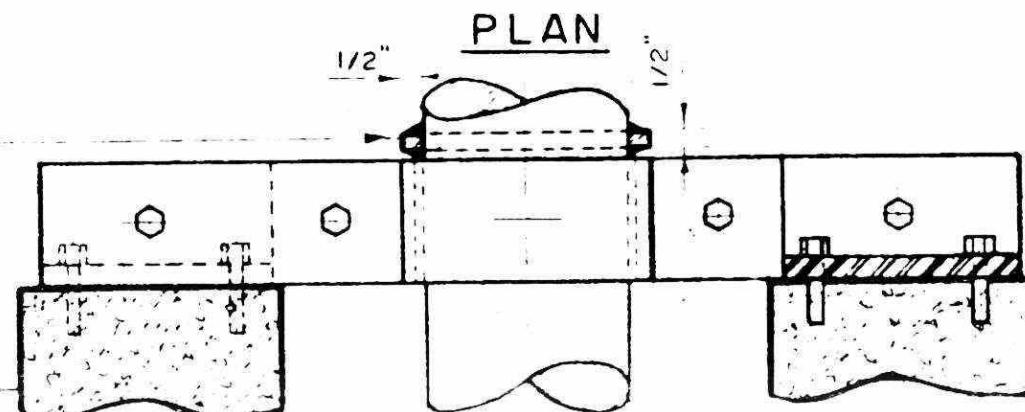
1/2" Ø x 4" LONG STAINLESS STEEL
BOLT, FILED THROUGH ANGLE
AND 3/8" THICK CLAMP BOLT
TOGETHER, (TYPICAL)

1/2" Ø x 3" LONG STAINLESS-STEEL
BOLT AND NUT, FILED THROUGH
CLAMP BOLT TOGETHER, (TYPICAL)



1/2" THICK STEEL COLLAR, WELD
TO 4" Ø DISCHARGE PIPE

CONCRETE SUPPORT FOR RISER
10" x 10" x 2'-8" HIGH - 2
SUPPORTS REQUIRED

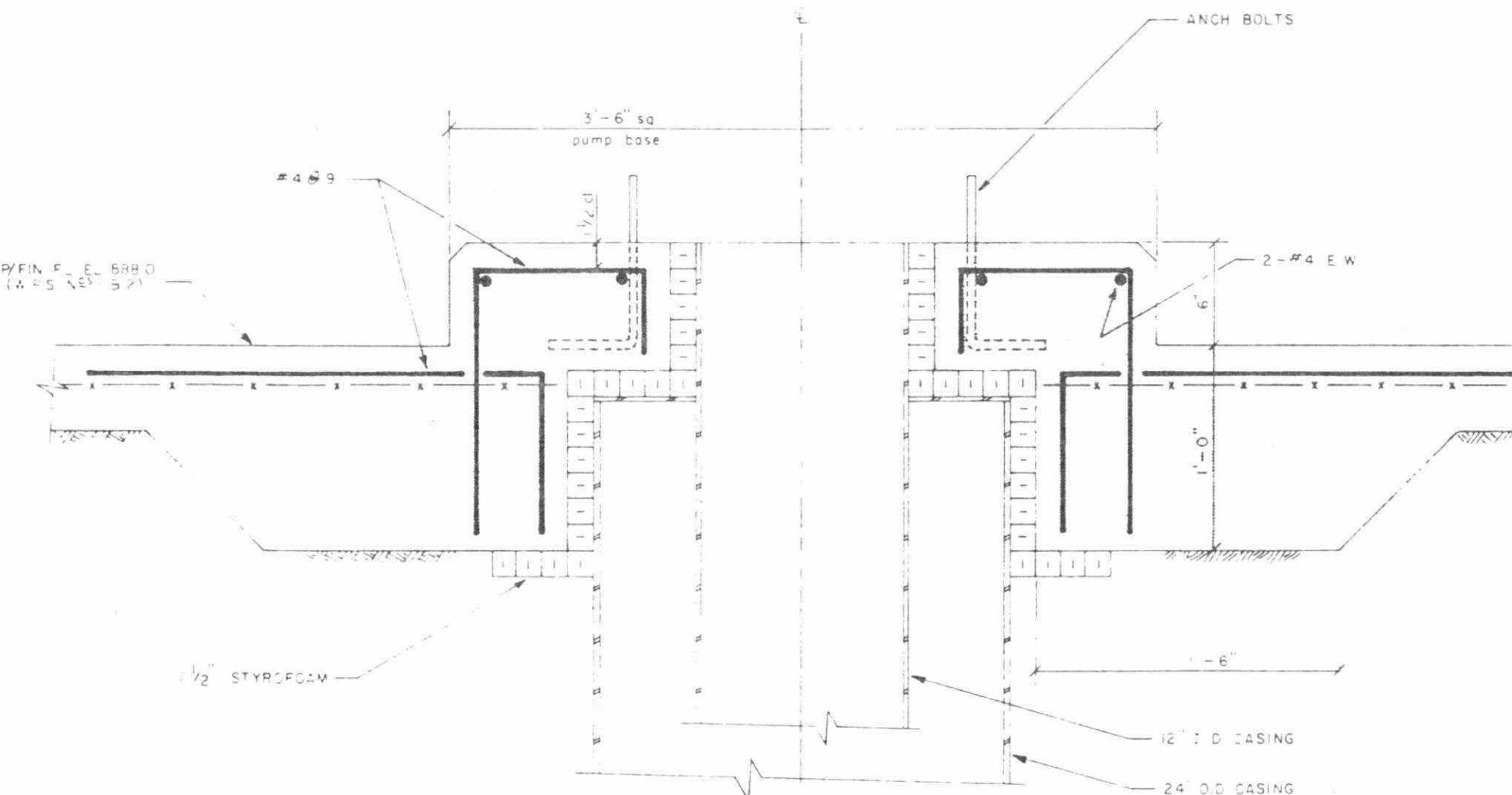


RISER CLAMP DETAILS

1/2" FLANGE

Figure 18: Pump Base Detail For Submersible Pump

3-39



PUMP BASE DETAIL

1/2" = 1'-0"

Figure 19: Pump Base Detail For Vertical Turbine Pump, Gravel Pack Well

SUBJECT:

WATER TREATMENT OPERATION

TOPIC: 4

Coagulation & Flocculation

OBJECTIVES:

The trainee will be able to:

1. Describe the need for coagulation and flocculation.
2. Explain the coagulation and flocculation process.
3. Identify the various methods of flash mixing.
4. Identify factors that affect the coagulation-flocculation process.
5. Describe the purpose of performing a jar test.

COAGULATION AND FLOCCULATION

GENERAL

Particulate impurities in water result from land erosion, pickup of minerals, and the decay of vegetation. Additional impurities are added by airborne contamination, industrial discharges, and by animal wastes. Thus, surface water sources, polluted by man and nature, are likely to contain suspended and dissolved organic and inorganic material, and biological forms such as bacteria and plankton.

These particulates, commonly called suspended solids, cover a broad size range. Larger sized particles such as sand and heavy silts can be removed from water by slowing down the flow to allow for simple gravity settling. These particles are often called settleable solids. Settling of larger sized particles occurs naturally when surface water is stored for a sufficient period of time in a reservoir or a lake. Smaller sized particles, such as bacteria and fine clays and silts, do not readily settle and treatment is required to produce larger particles that are settleable. These smaller particles are often called non-settleable solids or colloidal matter.

The purpose of coagulation and flocculation is to remove particulate impurities, especially non-settleable solids and colour from the water being treated. Non-settleable particles in water are removed by the use of coagulating chemicals.

In the coagulation process, chemicals are added which will initially cause the particles to become destabilized and clump

together. These particles gather together to form larger particles in the flocculation process.

With few exceptions, surface waters require treatment to remove particulate impurities and colour before distribution of water to the consumer.

COAGULATION

Coagulation is a physical and chemical reaction occurring between the alkalinity of the water and the coagulant added to the water which results in the formation of insoluble flocs.

For a specific coagulant such as aluminum sulfate the pH of the water determines which hydrolysis chemical compounds predominate. Lower pH values tend to favour positively charged compounds which are desirable for reacting with negatively charged colloids and particulates, forming insoluble flocs and removing impurities from the water.

The best pH for coagulation usually falls in the range of pH 5 to 7. The proper pH range must be maintained because coagulants generally react with the alkalinity in water. Residual alkalinity in the water serves to buffer a pH change in the system and aids in the complete precipitation of the coagulant chemicals. The amount of alkalinity in the raw water is generally not a problem unless the alkalinity is very low. Alkalinity may be increased by the addition of lime or soda ash.

Polymers are generally added in the coagulation process to stimulate or improve the formation of insoluble flocs.

Generally, the operator has no control over the pH and alkalinity of the raw water. Hence, evaluation of these water quality indicators may play a major role in selecting the type of chemical coagulants to be used at a particular water treatment plant or in changing the type of coagulant normally used if significant changes in pH and alkalinity occur in the raw water.

Overdosing as well as underdosing of coagulants may lead to reduced solids removal efficiency. This condition can be corrected by carefully performing jar tests and verifying process performance after making any changes in the operation of the coagulation process.

Coagulants

In practice, chemical coagulants are referred to either as primary coagulants or as coagulant aids. Primary coagulants are used to cause the particles to become destabilized and begin to clump together, while the purpose of coagulant aids is to add density to slow-settling flocs and add toughness so the floc will not break up in the following processes. In view of this definition, coagulant aids could also be called flocculation or sedimentation aids.

Metallic salts, such as aluminum sulfate (commonly called alum), ferric sulfate, ferrous sulfate and synthetic organic polymers (cationic, anionic, nonionic) are commonly used as coagulation chemicals in water treatment because they are effective; relatively low cost;

available; and easy to handle, store and apply.

When metallic salts such as aluminum sulfate or ferric sulfate are added to water, a series of reactions occur with the water and with other ions in the water. Sufficient chemical quantities must be added to the water to exceed the solubility limit of the metal hydroxide, resulting in the formation of a precipitate floc. The resulting floc formed will then adsorb on particles of turbidity in the water.

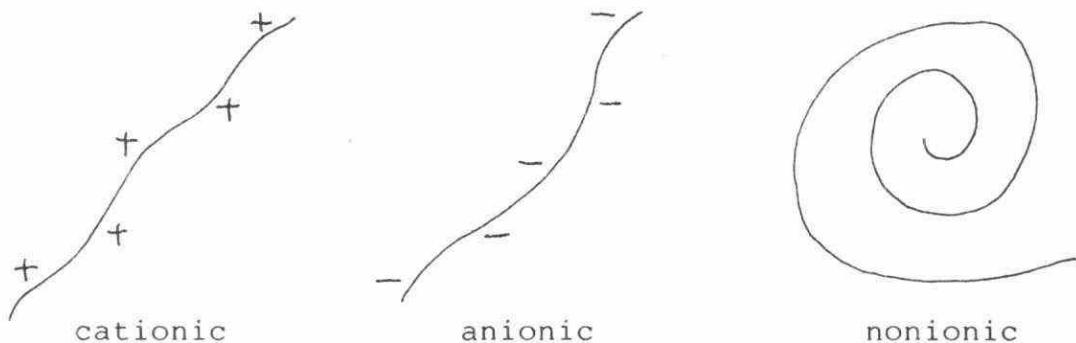
The synthetic organic polymers (cationic, anionic, nonionic) used in water treatment consist of a long chain of small subunits or "monomers". The polymer chain can have a linear or branched structure, ranging in length from a fraction of a micron (one micron = 0.001 millimeters) to as much as 10 microns. The total number of monomers in a synthetic polymer can be varied to produce materials of different Molecular Weights, which vary from about 100 to 10 000 000.

The polymers normally used in water treatment contain ionizable groups on the monomeric units and are commonly referred to as "polyelectrolytes". Polymers with positively charged groups on the monomeric units are referred to as "cationic" polyelectrolytes, while polymers with negatively charged groups are called "anionic" polyelectrolytes. Polymers without ionizable groups are referred to as "nonionic" polymers.

Cationic polymers have the ability to adsorb on negatively charged turbidity particles and neutralized their charge. Anionic, cationic and nonionic polymers also form interparticle

bridges, which aid in the collection and removal of particles from water by entrapping the particles.

Charged polyelectrolytes assume a stretch-out shape in solution while nonionic polyelectrolytes form a coil



While alum is perhaps the most commonly used coagulant chemical, cationic polymers are used in the water treatment field as both a primary coagulant, in place of metallic salts, and as a coagulant aid used in conjunction with metallic salts. Anionic and nonionic polymers have also proven to be effective in certain applications as coagulant aids and filter aids. A list of coagulants and coagulant aids are shown in Table 4-1.

TABLE 4.1 Chemical Coagulants used in Water Treatment

Chemical Name	Chemical	Primary Coagulant	Coagulant Aid
Aluminum Sulfate	$Al_2(SO_4)_3 \cdot 14H_2O$	X	
Ferrous Sulfate	$FeSO_4 \cdot 7H_2O$	X	
Ferric Sulfate	$Fe_2(SO_4)_3 \cdot 9H_2O$	X	
Ferric Chloride	$FeCl_3 \cdot 6H_2O$	X	
Cationic Polymer	Various	X	X
calcium Hydroxide	$Ca(OH)_2$	X*	X
Calcium Oxide	CaO	X*	X
Sodium Aluminate	$Na_2Al_2O_4$	X*	X
Bentonite	Clay		X
Calcium Carbonate	$CaCO_3$		X
Sodium Silicate	Na_2SiO_3		X
Anionic Polymer	Various		X
Nonionic Polymer	Various		X

*Used as primary coagulants only in water-softening processes

Flash Mixing

It is desirable to complete the coagulation reaction in as short a time as possible. Several seconds is common since the reaction time is short. Several methods of flash mixing can be used (see Figure 4-1):

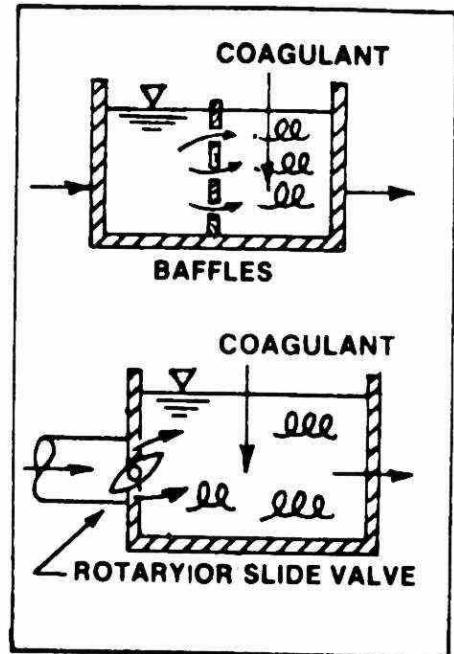
- 1) Hydraulic mixing using flow energy in the system
- 2) Mechanical mixing
- 3) Diffusers and grid systems, and
- 4) Pumped blenders

Hydraulic mixing with baffles or throttling valves works well in systems which have sufficient water velocity to cause turbulence in the water being treated. The turbulence in the flowing water mixes the chemicals with the water.

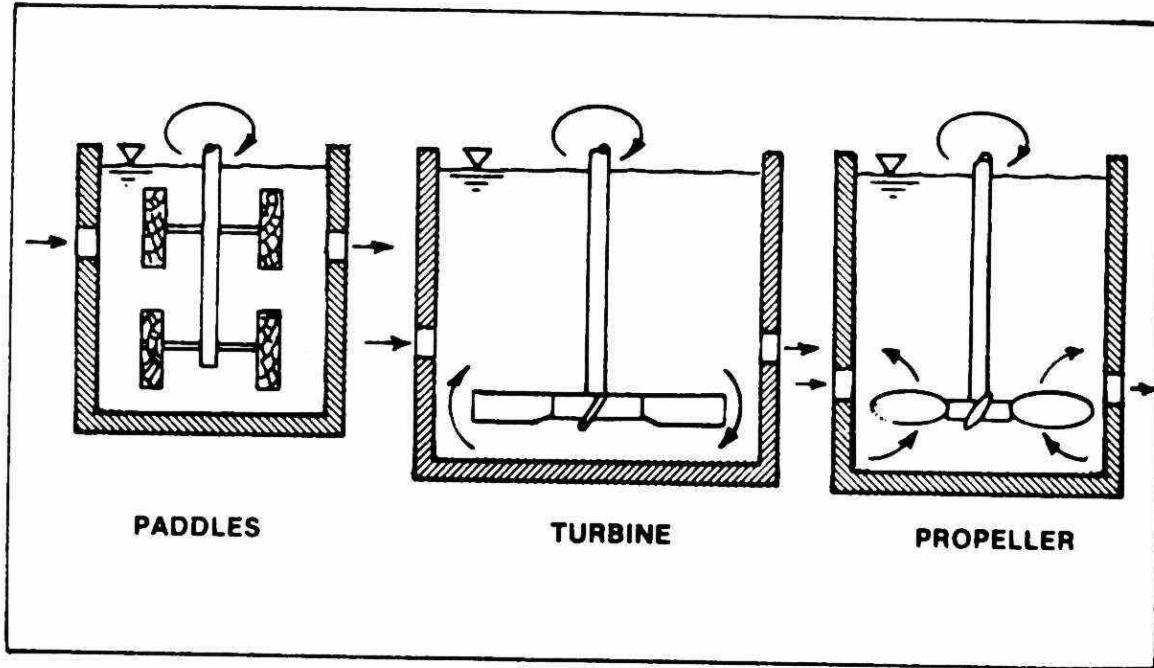
Mechanical mixers (paddles, turbines and propellers) are frequently used in coagulation facilities. Mechanical mixers are versatile and reliable; however, they generally use the greatest amount of electrical energy for mixing the coagulant with the water being treated.

Diffusers and grid systems consisting of perforated tubes or nozzles can be used to disperse the coagulant into the water being treated. These systems can provide uniform distribution of the coagulant over the entire coagulation basin. However, they are generally sensitive to flow changes and may require frequent adjustments to produce the proper amount of mixing.

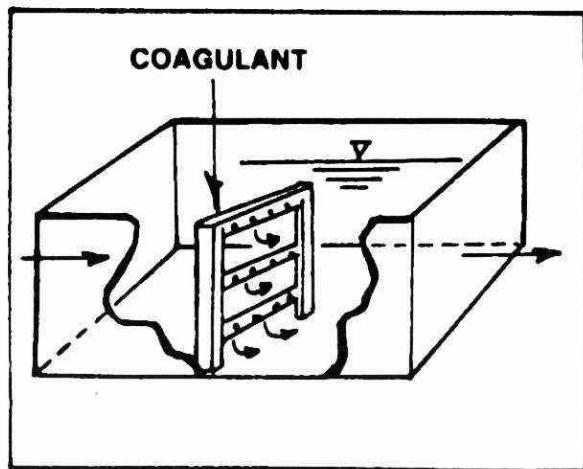
Pumped blenders (Figure 4-2) have also been used for mixing in coagulation facilities. The coagulant is added directly to the water being treated through a diffuser in a pipe. This can provide rapid dispersion of the coagulant and does not create any significant headloss in the system. Electrical energy consumption is considerably less than that of a comparable mechanical mixer.



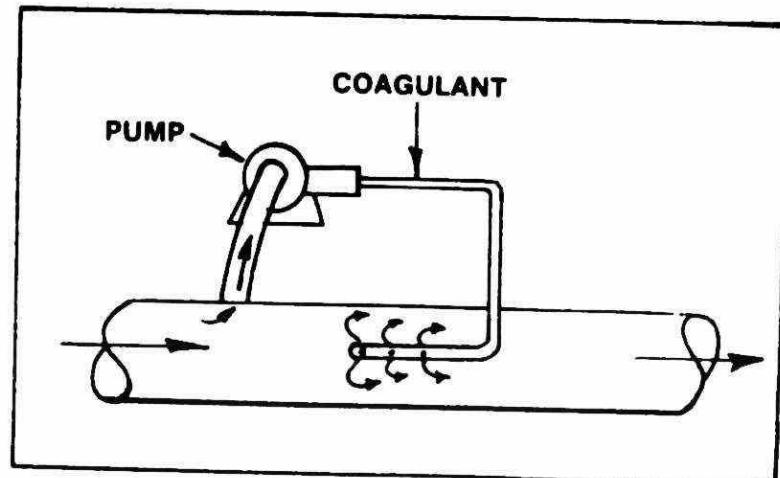
HYDRAULIC
(eee - DENOTES TURBULENCE)



MECHANICAL MIXERS
(INSTALLED IN MIXING BASINS)



DIFFUSER



PUMPED BLENDER

Figure 4-1

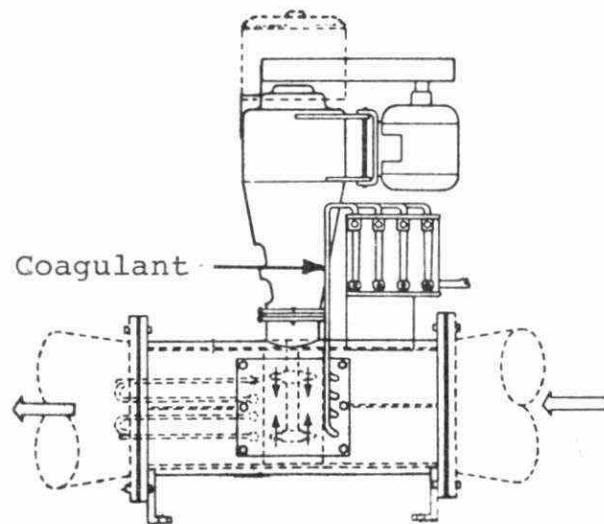


Figure 4-2

Inline Mixer or Blender (Detention

Time = 1 - 2 sec)

FLOCCULATION

Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles. The flocculation process provides contact between particles to promote their gathering together into floc for ease of removal by sedimentation and filtration. The collisions between particles result from gentle stirring created by a mechanical or hydraulic means of mixing.

Floc formation is controlled by the rate at which collisions occur between particles and by the effectiveness of these collisions in promoting attachment between particles. The purpose of flocculation is to create a floc of a good size, density, and toughness for later removal in the sedimentation and filtration

processes. The best floc size ranges from 0.1 mm to about 3 mm, depending on the type of removal processes used. A sketch showing floc formation is shown in (Figure 4-3).

Figure 4-3

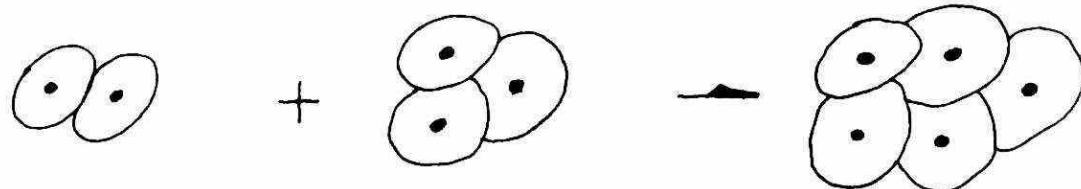
Floc Formation



alum complex suspended matter neutralized
positive charge negative charge particle

Coagulation

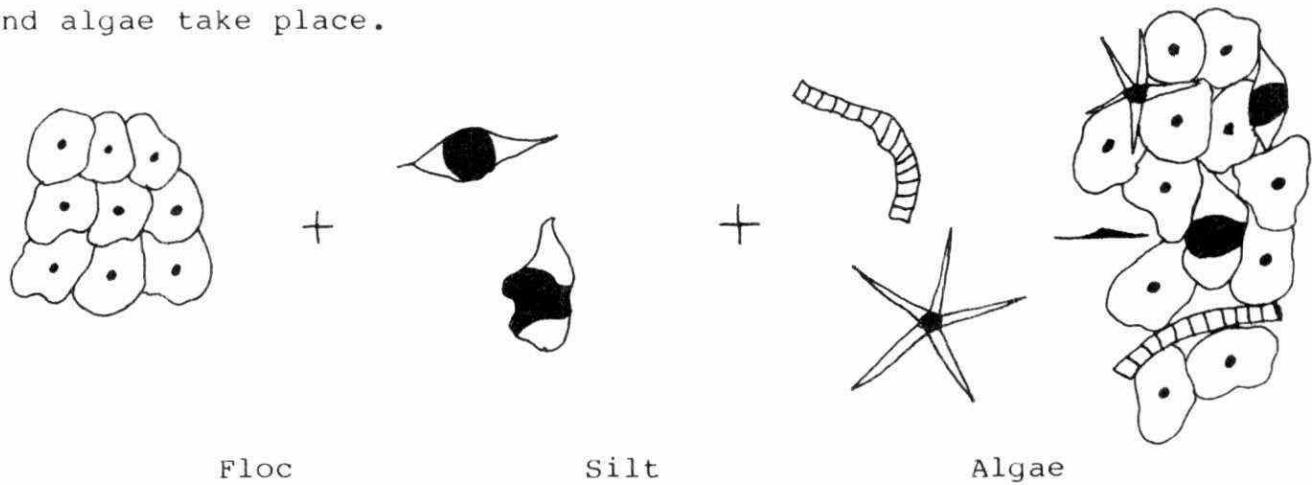
Initial floc is formed



Flocculation

Floc increases in mass through constant
collisions

As the floc grows, collisions with coarser suspended material and algae take place.



If algae are present in large numbers in the water, the floc will have a "stringy" appearance.

Although the floc formed contains most of the suspended matter in the water, it is still made up of approximately 96% water. Because of this, it is very fragile and must be treated gently. This means that high speed flocculation must be avoided.

An efficient flocculation process involves the selection of the right stirring time (detention time), the proper stirring intensity, a properly shaped basin for uniform mixing, and mechanical equipment or other means of creating the stirring action.

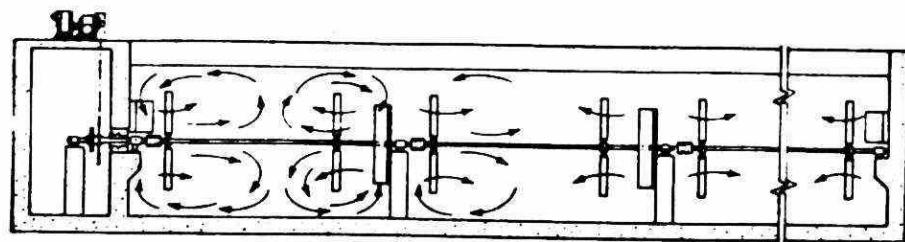
Detention time is usually not a critical factor in the coagulation or flash-mixing process, if the chemical coagulants

are satisfactorily dispersed into the water being treated and mixed for at least several seconds. Detention time is required for the necessary chemical reactions to take place. Some operators have been able to reduce coagulant dosages by increasing the amount of detention time between the point of addition of the coagulant and the flocculation basins. In the flocculation process, however, detention time is quite important. The minimum detention time recommended for flocculation ranges from about 5 to 20 minutes for direct filtration systems and up to 30 minutes for conventional filtration. The size and shape of the flocculation facility also influences the detention time needed for optimum floc development.

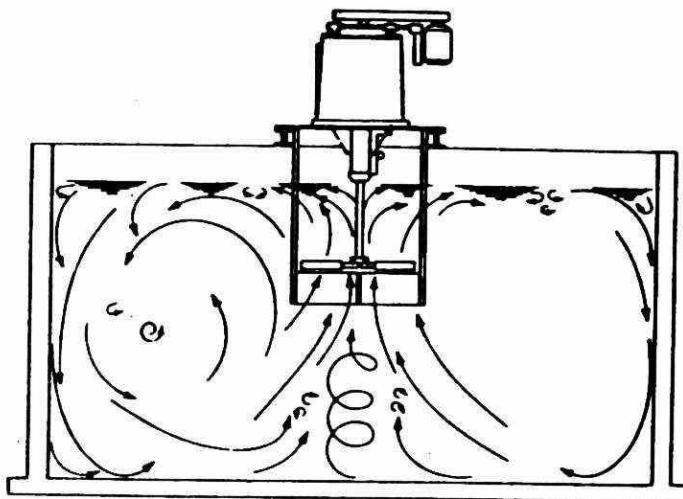
Flocculators

Two types of mechanical flocculators are commonly installed, horizontal paddle wheel types and vertical flocculators (see Figure 4-4). Both types can provide satisfactory performance; however, the vertical flocculators usually require less maintenance since they eliminate submerged bearings and packings. Vertical flocculators can be of the propeller, paddle, or turbine types.

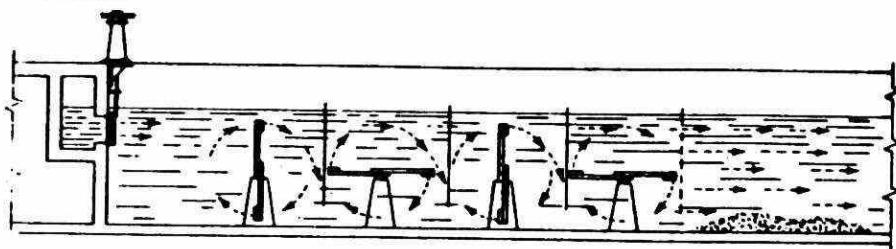
The best flocculation is usually achieved in more than one compartmentalized basin rather than one equivalent-sized basin. The compartments are separated by baffles to prevent short-circuiting of the water being treated, and to reduce the level of turbulence in each succeeding compartment by reducing the



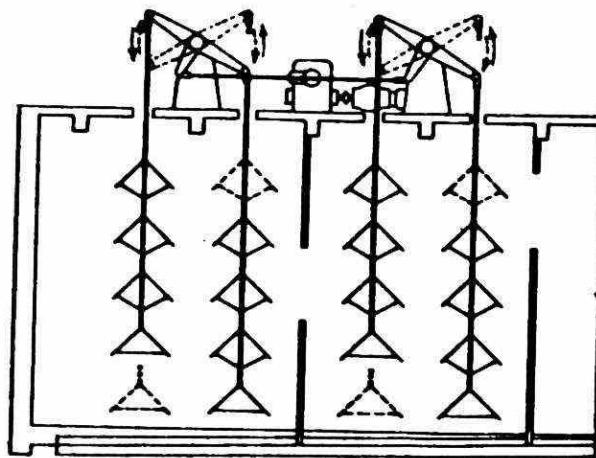
propeller flocculator.



Turbine flocculator. This device is easy to install in existing basins.

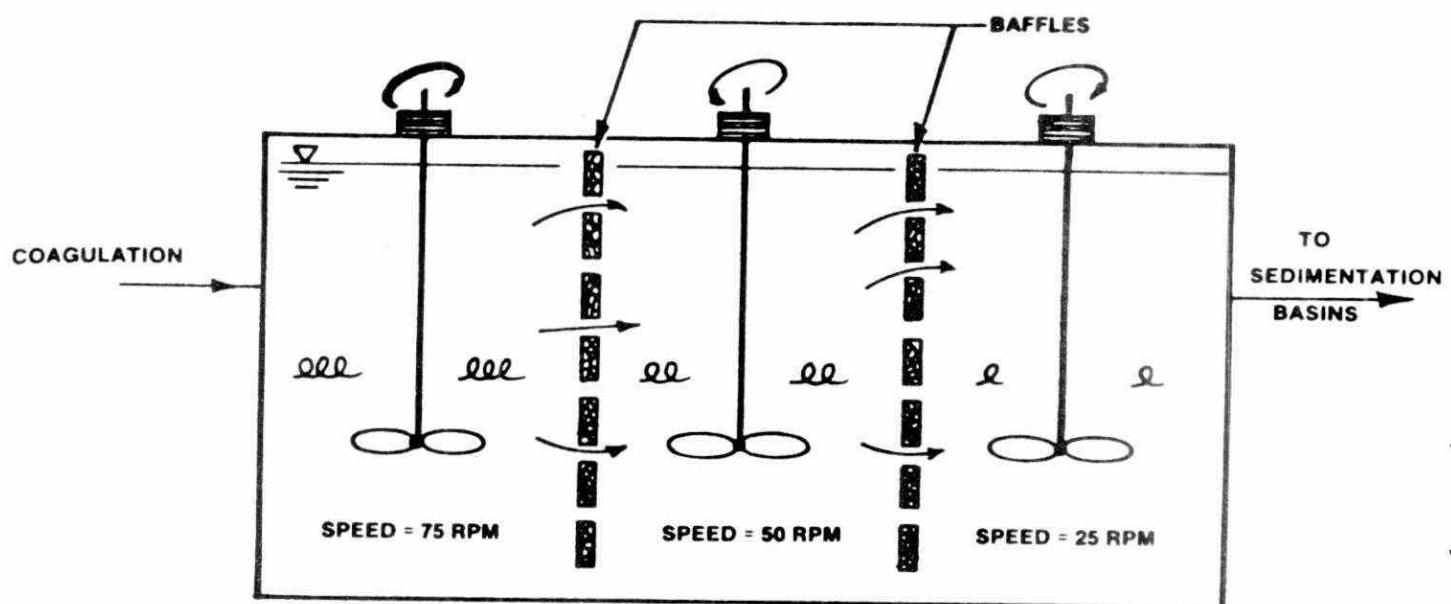


Flocculating equipment. A series of paddles placed transversely across the tank width are arranged to impart a barrel-roll motion to the water.



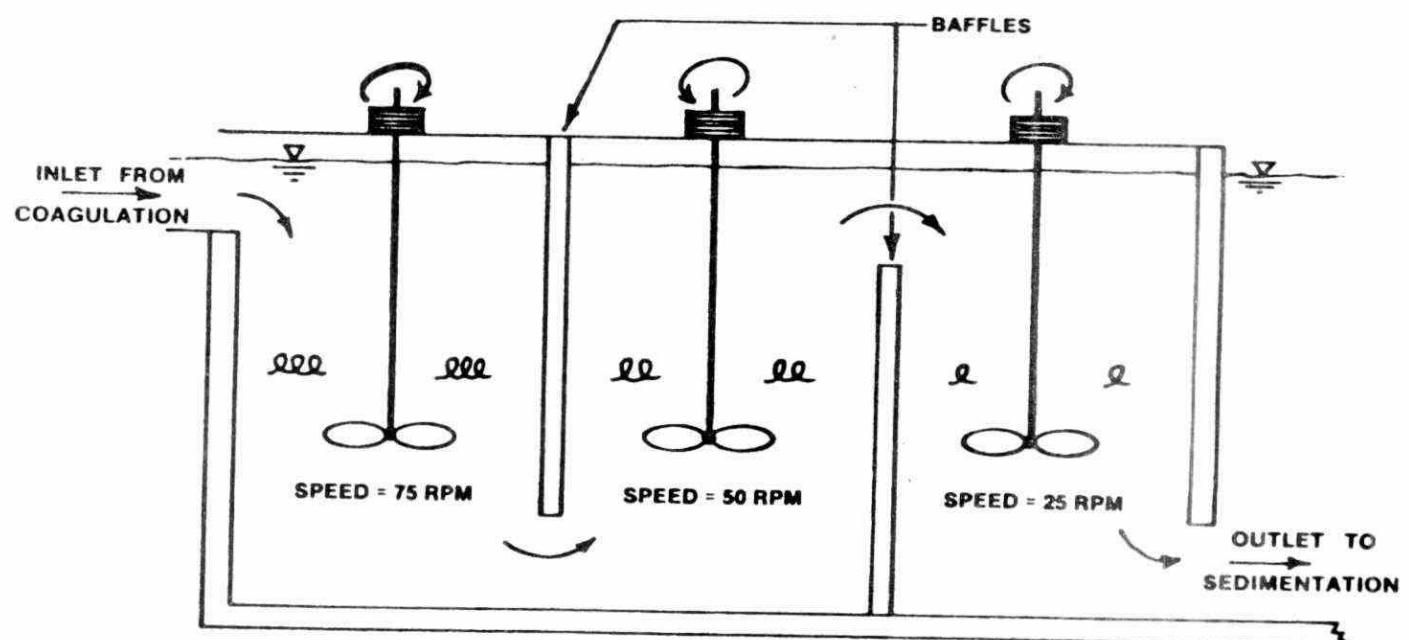
Walking beam flocculator. The up-and-down motion of the paddles provides gentle agitation.

Figure 4-4 Flocculators



LEGEND:

(ooo - DENOTES TURBULENCE)



LEGEND:

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Figure 4-5

speed of the stirrers, as shown in (Figure 4-5), or reducing the area of the paddles. This is called "tapered-energy mixing". The reason for reducing the speed of the stirrers is to prevent breaking apart the large floc particles which have already been formed. Breaking up the floc will not accomplish anything and will overload the filters.

THE COAGULATION/FLOCCULATION PROCESS

The need for the coagulation and flocculation processes are required to precondition or prepare non-settleable particles present in the raw water for removal by sedimentation and filtration. Small particles, without proper coagulation and flocculation are too light to settle out and will not be large enough to be trapped during filtration. In this regard it is convenient to consider coagulation-flocculation as one treatment process.

Since the purpose of coagulation-flocculation is to promote particulate removal, the effectiveness of the sedimentation and filtration processes, as well as overall plant performance, depends upon successful coagulation-flocculation. Disinfection of the water can also be affected by poor coagulation-flocculation performance. Bacteria and other disease-causing organisms can be bound up in suspended particles and thereby shielded from disinfection, if the solids removal processes before final disinfection, especially filtration are ineffective. Effective

coagulation-flocculation promotes the removal of natural organic compounds. Removal of these compounds will reduce the formation of trihalomethanes following the use of chlorine for disinfection.

PROCESS CONTROL

In theory, the chemical reactions and the formation of floc associated with the coagulation-flocculation process are rather complex. Yet from a practical viewpoint the operator of a water treatment plant must be able to measure and control the performance of these processes on a day-to-day basis.

The most important consideration in coagulation-flocculation process control is selection of the proper type and amount of coagulant chemical(s) to be added to the water being treated. This determination is commonly made in the laboratory with the aid of a jar testing apparatus. When selecting a particular type of coagulant chemical, consideration must be given to the quantity and solids content of the sludge created and the means of ultimate disposal. Jar tests should be run at least daily and more often when the quality of the raw water changes. Changes in the raw water may require changes in the amount of chemical and/or type of chemical.

JAR TESTING

For a simple illustrated step-by-step procedure on how to run a "standard" jar test, see Topic 12.

It should be realized that it is almost impossible to duplicate in the jar test exactly the flow conditions that are occurring in the treatment plant. The jar test attempts to duplicate in the laboratory what is occurring in the plant in relationship to detention times, mixing and settling conditions. By watching the jar test floc form and settle, the operator can get a good idea of what should happen in the plant for the test chemical dose. The jar test should be used as an indication of what to expect in the water treatment plant. By closely watching the floc form in the flocculators and settle out in the sedimentation basin of the plant, the operator can also get a good indication of whether the best coagulant dosage has been chosen.

Also by observing the performance of the filters and by looking at the laboratory test results, the operator will gain additional information that will help make the necessary adjustments to the actual chemical feed rates.

Jar Test Evaluation

Several factors are important in evaluating jar test results. These factors include:

- 1) Rate of floc formation
- 2) Type of floc particles
- 3) Clarity of water between floc particles
- 4) Size of floc
- 5) Amount of floc formed

- 6) Floc settling rate, and
- 7) Clarity of water above the settled floc

Visible floc formation should begin shortly after the flashmix portion of the jar test. During flocculation mixing, a number of small particles will gradually clump together to form larger particles. Floc particles that are discrete and fairly dense in appearance are usually better than floc particles that have a light, fluffy appearance. Large floc is impressive but it is neither necessary nor always desirable. Large, light floc does not settle as well as smaller, denser floc and it is more subject to breaking up by paddles and water turbulence.

The quantity of floc formed is not as critical as floc quality or clarity of the settled water produced. The water between the floc particles should be clear and not hazy nor milky in appearance. The best chemical dosage is one which produces a finished water that meets Ontario Drinking Water Objectives at the lowest cost. Another important consideration is the amount of sludge produced. Smaller amounts of sludge are desirable to reduce sludge handling and disposal requirements. Most of the sludge volume consists of precipitates of the added chemicals rather than suspended solids.

The rate at which the floc settles after mixing has stopped is another important consideration. The floc should start to settle as soon as the mixer is turned off, and should be almost completely (80 to 90 percent) settled after about 15 minutes.

Floc that remains suspended longer than 15 to 20 minutes in the jar test, is not likely to settle out in the sedimentation basin, and will increase the load on the filter.

If the floc starts to settle before mixing is completed, or more than 80 percent of the floc has settled within one or two minutes after mixing has stopped, the floc is too heavy. In your water treatment plant, this can result in the floc settling out in the flocculation basins rather than in the sedimentation basins. This is a rather rare occurrence and indicates that too much chemical has been added.

There is no substitute for experience in evaluating jar test data. Therefore, it is recommended that jar tests be performed regularly during periods of high raw water turbidity, even if the plant is producing good quality finished water at the time. This will provide a basis for comparing coagulation-flocculation effectiveness under different conditions and allow "fine-tuning" of the chemical treatment to achieve the best efficiency. Jar tests of flash-mixer water samples should be performed regularly at the start of every shift and more frequently during periods of high turbidity in the raw water. The results of these tests may give an early warning impending treatment process problems.

Always verify the effectiveness of a change in treatment based upon jar test results. To verify jar test results with treatment plant performance, obtain a water sample just downstream from the flash mixer. Collect the sample after sufficient time has passed for the treatment change to take effect. This sample

should be mixed by the jar test apparatus under the same conditions that the original raw water sample was mixed.

Jar tests are an effective tool for predicting the results of chemical treatment alternatives. However, jar test results are useless unless applied and verified in your treatment plant.

Applying Jar Test Data

After evaluation of the jar test results, apply the dosage used to achieve the best jar test results to your water treatment plant operation.

The settings on chemical feeders will depend on whether you are using a dry chemical feeder or a liquid chemical feeder.

Refer to Sections A and J in the Mathematics for Water & Wastewater Operations Manual for actual examples and calculations.

One of the best ways to evaluate the performance of your coagulation-flocculation process is to observe the actual process. When you walk through the treatment plant, take some clear beakers. Dip some water out of each stage of the treatment process. Hold the sample up to a light and look at the clarity of the water between the floc and study the shape and size of the floc. Study the development of the floc from one flocculation chamber to the next and into the sedimentation basin.

- 1) Observe the floc as it enters the flocculation basins. The floc should be small and well-dispersed throughout the flow. If not,

the flash mixer may not be providing effective mixing or the chemical dose or feed rate may be too low.

- 2) Tiny alum floc may be an indication that the chemical coagulant dose is too low. A "popcorn flake" is a desirable floc appearance. If the water has a milky appearance or a bluish tint, the alum dose is probably too high.
- 3) What does the floc look like as it moves through the flocculation basins? The size of the floc should be increasing. If the floc size increases and then later starts to break up, the mixing intensity of the downstream flocculators may be too high. Try reducing the speed of these flocculators, or increasing the polymer dosage.
- 4) Does the floc settle out in the sedimentation basin? If a lot of floc is observed flowing over the weirs, the floc is too light for the detention time produced by that flow rate. By increasing the chemical coagulant dose or adding a coagulant aid such as a polymer, a heavier larger floc may be produced. The appearance of fine floc particles washing over the effluent weirs could be an indication of too much alum and

the dose should be reduced.

5) In summary, use the procedures that best suit your needs. Only change one operational variable at a time and wait to analyze the results before changing another variable. Keep good records. Evaluate the performance of your plant and adjust your procedures as necessary.

PROCESS TROUBLESHOOTING

Changes in source water turbidity levels, either increases or decreases, generally require that the operator verify the effectiveness of the coagulant chemicals and dosages being applied at the flash mixer. This is best accomplished by performing a series of jar tests as discussed previously. You must realize that decreasing raw water turbidity levels can be just as upsetting to the process as increasing levels.

Visual observations of flash-mixing intensity as well as the condition of the floc in the flocculation basins may also indicate the need for process changes such as adjustment or mixer speed or coagulant dosage.

Alkalinity, pH and temperature changes in the source water quality may have an impact on the clumping together of floc during the coagulation-flocculation process. In addition, water temperature changes may require an adjustment in the level of mixing intensity in flash mixers or flocculators. Temperature

changes are usually gradual over time, thus large process adjustments are seldom necessary.

Sudden increases in filtered water turbidity could be caused by poor filter performance. However, poor coagulation flocculation performance is usually the culprit, and the operator must take immediate action to correct the problem, remembering that several hours may pass before changes in the operation of the coagulation-flocculation process are seen in the filter effluent. One quick remedy may be to feed a filter-aid chemical such as a nonionic polymer directly to the filter influent. While this may solve the short-term problem only changes in the coagulation-flocculation process will enhance long-term plant performance. Again, the results for laboratory jar tests should be used as the basis for making process changes. Filter-aid chemicals are discussed further in the topic on "Filtration".

The following table is a summary of coagulation-flocculation process problems, how to identify the causes of these problems and also how to go about trying to correct the problem.

Process Troubleshooting Guide

Source Water Quality Changes	Operator Actions	Possible Process Changes
<ul style="list-style-type: none"> - Turbidity - Temperature - Alkalinity - pH - Color 	<ol style="list-style-type: none"> 1. Perform necessary analyses to determine extent of change. 2. Evaluate overall process performance. 3. Perform jar tests if indicated. 4. Make appropriate process changes (see right hand column, Possible Process Changes.) 5. Increase frequency of process monitoring 6. Verify response to process changes at appropriate time (be sure to allow sufficient time for change to take effect). 	<ol style="list-style-type: none"> 1. Change coagulant(s). 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Add coagulant aid or filter aid. 5. Adjust alkalinity or pH.
Coagulation Process Effluent Quality Changes	Operator Actions	Possible Process Changes
<ul style="list-style-type: none"> - Turbidity - Alkalinity - pH 	<ol style="list-style-type: none"> 1. Evaluate source water quality. 2. Perform jar tests if indicated. 3. Verify process performance: (a) Coagulant feed rate(s), (b) Flash mixer operation. 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time. 	<ol style="list-style-type: none"> 1. Change coagulant(s). 2. Adjust coagulant dosage. 3. Adjust flash mixer intensity (if possible) 4. Adjust alkalinity or pH.
Flocculation Basin Floc-Quality Changes	Operator Actions	Possible Process Changes
<ul style="list-style-type: none"> - Floc formation 	<ol style="list-style-type: none"> 1. Observe floc condition in basin: <ul style="list-style-type: none"> (a) Dispersion, (b) Size and (c) Floc strength (breakup). 2. Evaluate overall process performance. 3. Perform jar tests if indicated: <ul style="list-style-type: none"> (a) Evaluate floc size, settling rate and strength. (b) Evaluate quality of supernatant; turbidity, pH, and color. 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time. 	<ol style="list-style-type: none"> 1. Change coagulant 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Add coagulant aid. 5. Adjust alkalinity or pH.

TABLE 4 - 2

SUBJECT

WATER TREATMENT OPERATION

TOPIC: 5

Sedimentation

OBJECTIVES:

The Trainee will be able to:

1. List the purposes of sedimentation.
2. Describe the various types of sedimentation basins and how they work.
3. Identify factors affecting the sedimentation process.

Sedimentation

PROCESS DESCRIPTION

The purposes of the sedimentation process are to remove suspended solids that are denser than water and to reduce the load on the filters. The suspended solids may be in their natural state, such as bacteria, clays, silts or they may be pre-conditioned by prior treatment in the coagulation-flocculation process to form floc or may be precipitated impurities. (Hardness and iron precipitates formed by the addition of chemicals).

Sedimentation is accomplished by decreasing the velocity of the water being treated below the point where it can transport settleable suspended material, thus allowing gravitational forces to remove particles held in suspension. When water is almost still in sedimentation basins, settleable solids will move towards the bottom of the basin.

PRESEDIMENTATION

Settling of a larger-sized particles occurs naturally when surface water is stored for a sufficient period of time in a reservoir or a natural lake. Gravitational forces acting in the lake accomplish the same purpose as sedimentation in the water treatment plants; larger particles such as sand and heavy silts settle to the bottom.

Debris dams, grit basins or sand traps can also be used to remove some of the heavier particles from source water. The

facilities may be located upstream from the reservoir, treatment plant intake or diversion facilities, and serve to protect the municipal intake pipeline from siltation. Grit basins may be located between the intake structure and the coagulation flocculation facilities (Fig. 5-1). Thus, presedimentation facilities such as debris dams, impoundments and grit basins reduce the solids-removal load at the water treatment plant. At the same time, they provide an equalizing basin which evens out fluctuations in the concentration of suspended solids in the source water.

Presedimentation facilities are often installed in locations where the source water supply is diverted directly from rivers or streams which can be contaminated by overland runoff and point source waste discharges. Ideally, surface waters should be stored in a reservoir and transported directly to the water treatment plant in a pipeline. In a reservoir the heavier solids can settle out before they reach the plant. However, geographical, physical and economic considerations often make this alternative impractical.

FACTORS AFFECTING THE SEDIMENTATION PROCESS

The size, shape and weight of the particles to be settled out, as well as physical and environmental conditions in the sedimentation tank, have a significant impact on the type of pre-treatment needed and the sedimentation process efficiency.

Factors affecting particle settling include:

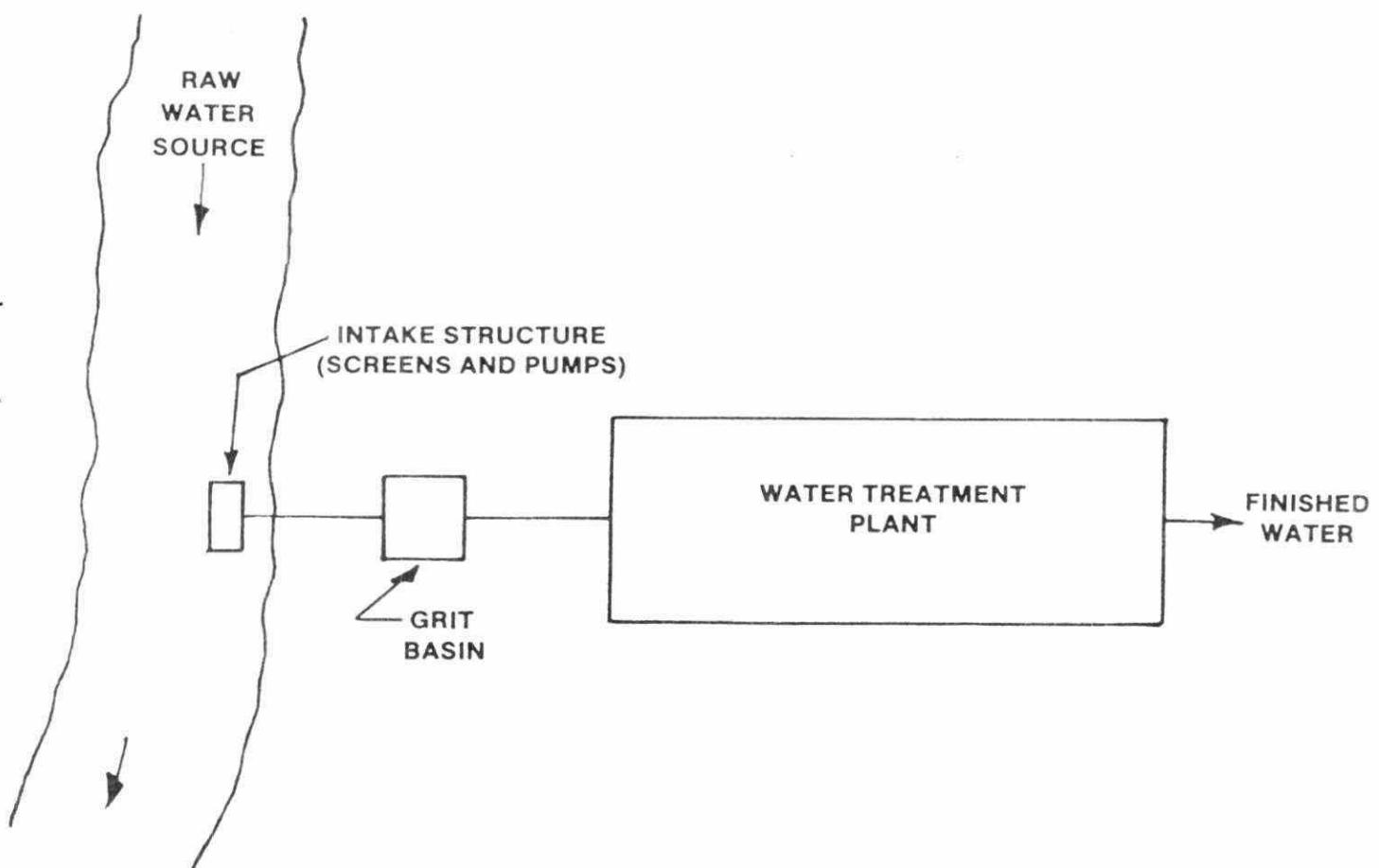
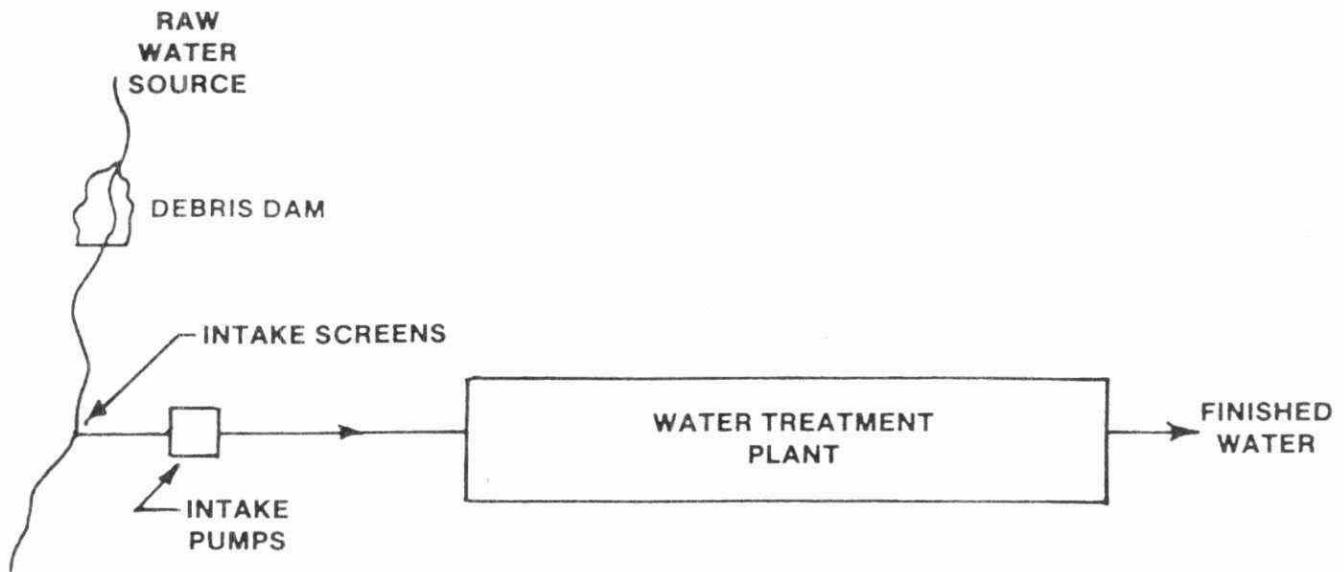


Figure 5-1 Presedimentation facilities

1. Particle size and distribution
2. Shape of particles
3. Density of particles
4. Temperature (viscosity and density)
of the water
5. Electrical charges on particles
6. Dissolved substances in water
7. Flocculation characteristics of the
suspended material
8. Environmental conditions (such as wind)
9. Sedimentation basin hydraulic and design
characteristics (such as inlet conditions
and shape of basin)

Particle Size, Distribution and Shape

Because of their size and density, sand and silt particles greater than 10 microns in diameter (1 micron = 0.001 mm) can be removed from water by sedimentation. Finer particles do not readily settle and treatment is required to produce larger, denser particles (floc) that are settleable (see Table 5-1).

The shape of particles influences particle settling also. Smooth circular particles will settle quicker than irregular shaped particles with ragged edges.

Most particles have very slight electrical charge. If all of the particles have a negative charge, they will tend to repel each

other and not settle. Since alum consists of aluminum with a positive charge, the negatively charged particles are attracted to the positively charged aluminum ions. This causes the clumping together which helps the particles to settle out.

TABLE 5-1 TYPICAL SIZE OF PARTICLES IN SURFACE WATERS

SOURCE	DIAMETER OF PARTICLE (microns)
Coarse Turbidity	11 - 1 000
Algae	3 - 1 000
Silt	10
Bacteria	0.3 - 10
Fine Turbidity	0.1 - 1
Viruses	0.02 - 0.26
Colloids	0.001 - 1

Temperature

Another consideration in sedimentation is the effect of water temperature changes. The settling velocity of a particle becomes much slower as the temperature drops. The colder the water temperature becomes, the longer the particles take to settle out. This means that the longer time periods are required for effective settling at colder water temperatures, or that chemical dosages must be adjusted for the slower settling velocities.

Currents

Several types of currents are found in the typical sedimentation basin:

1. Surface currents caused by winds
2. Density currents caused by differences in suspended solids concentrations and temperature differences, and
3. Eddy currents produced by the flow of the water entering and exiting the basin

Currents in the sedimentation basin are beneficial to the extent that they promote flocculation. Collectively, however, these currents distribute the suspended particles unevenly throughout the basin, thereby reducing the expected performance of the sedimentation basin.

Some of these currents can be substantially reduced in the design of a treatment plant by providing baffled inlets and other hydraulic control features. Wind-induced currents, can only be eliminated by providing covers or suitable windbreaks for the sedimentation basins. In most instances, basin covers are not economically feasible nor necessarily desirable from an operations and maintenance standpoint.

SEDIMENTATION BASIN ZONES

For convenience in discussing sedimentation basins, a typical sedimentation basin can be divided into four zones (see Figure 5-2):

1. Inlet zone
2. Settling zone
3. Sludge zone, and
4. Outlet zone

The inlet to the sedimentation basin should provide a smooth transition from the flocculation basin and should distribute the flocculated water uniformly over the entire cross-section of the basin. A properly designed inlet such as a perforated baffle wall (see Figure 5-3) will significantly reduce short circuiting of water in the basin, and will minimize the effects of the water wanting to flow at the inlet velocity straight through the basin.

The settling zone is the largest portion of the sedimentation basin. This zone provides calm, undistributed storage of the flocculated water for a sufficient time period to permit effective settling of the suspended particles in the water being treated.

The sludge zone is located at the bottom of the sedimentation basin and is a temporary storage place for the settled particles. also the sludge zone is used to allow for compression settling of the sludge.

Basin inlet structures should be designed to minimize high flow velocities near the bottom of the sedimentation basin which

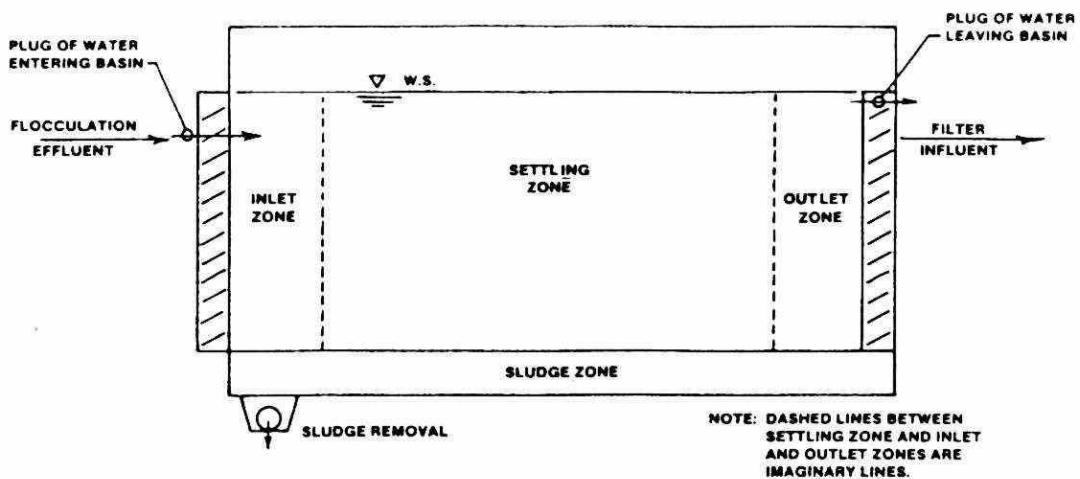


Figure 5-2 Sedimentation basin zones

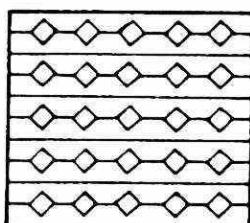
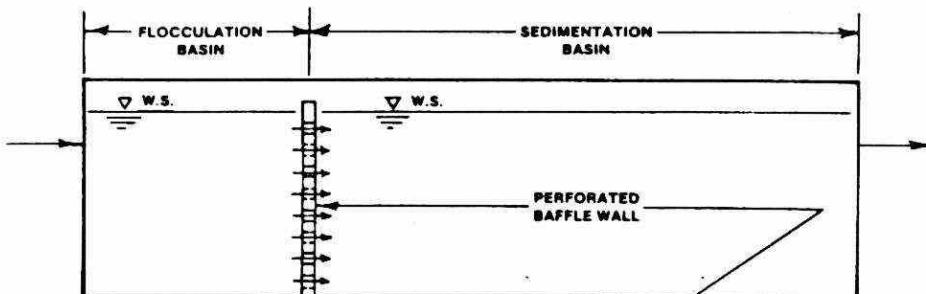


Fig. 5-3 Sedimentation basin and inlet baffle wall

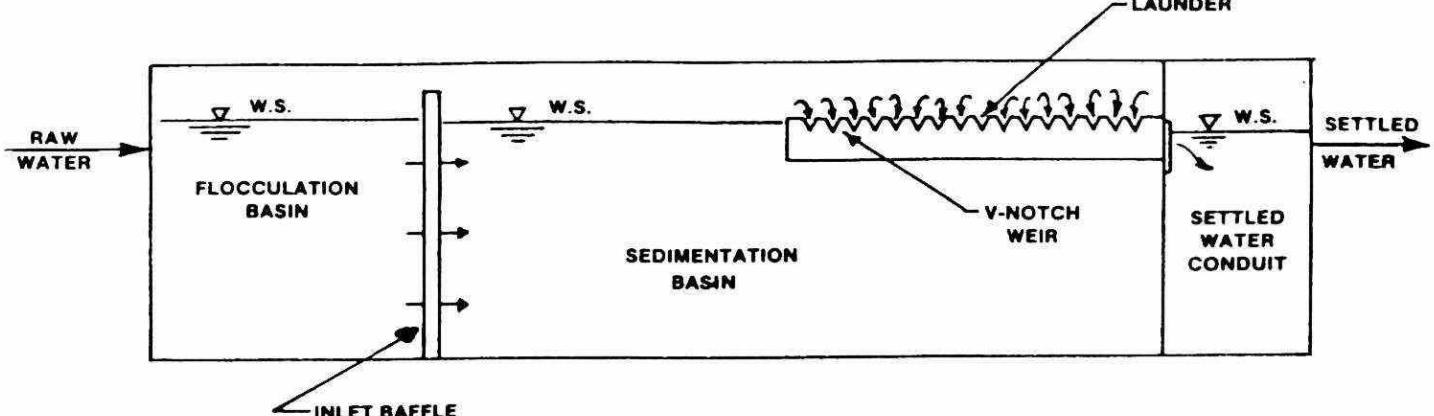


Figure 5-4 Typical sedimentation basin outlet (flow over V-notch weirs)

could distribute or scour settled particles in the sludge zone, causing them to become resuspended.

Sludge is removed from the sludge zone by scraper and vacuum devices which move along the bottom of the sedimentation basin as necessary or on a regularly scheduled basis. Some plants require that the basin be drained and flushed to remove the sludge if the removal devices do not operate the entire length of the basin.

The basin outlet should provide a smooth transition from the sedimentation basin to the settled water conduit or channel. The outlet can also control the water level in the basin.

Skimming or effluent troughs, commonly referred to as launders are frequently used to uniformly collect the settled or clarified water. Adjustable V-notch weirs are generally attached to the launders to enable a uniform draw-off of basin water by controlling the flow. If the water leaving a sedimentation basin flows out unevenly over the weirs or at too high a velocity, floc can be carried over to the filters.

SEDIMENTATION BASIN TYPES

Rectangular sedimentation basins are commonly found in many large-scale water treatment plants. Rectangular basins are popular for the following reasons:

1. High tolerance to shock loading (water quality changes)
2. Predictable performance

3. Cost-effectiveness
4. Low maintenance, and
5. Minimal short-circuiting

Double-deck basins (see Figure 5-6) are an adaption of the rectangular basin design. By stacking one basin on top of another, double-deck basins provide twice the effective sedimentation surface area of a single basin of equivalent land area. Double-deck basins are designed to conserve land area, but are not in common use owing partially to higher operator and maintenance costs. In this design, sludge removal equipment must operate in both decks, and the entire operation may have to be shut down if an equipment problem develops in either deck.

Circular or square, horizontal-flow basins, as shown in (Figure 5-5) are often referred to as clarifiers. These basins share some of the performance advantages of rectangular basins; however, they are generally more likely to have short-circuiting and particle removal problems. One of the major problems with square settling basins is the removal of sludge from the corners. Some circular clarifiers are also called "Suspended Solids Contact Clarifiers".

High-rate or tube settlers were developed to increase the settling efficiency of conventional rectangular sedimentation basins. They have also been installed in circular basins with successful results.

Water enters the inclined settler tubes and is directed

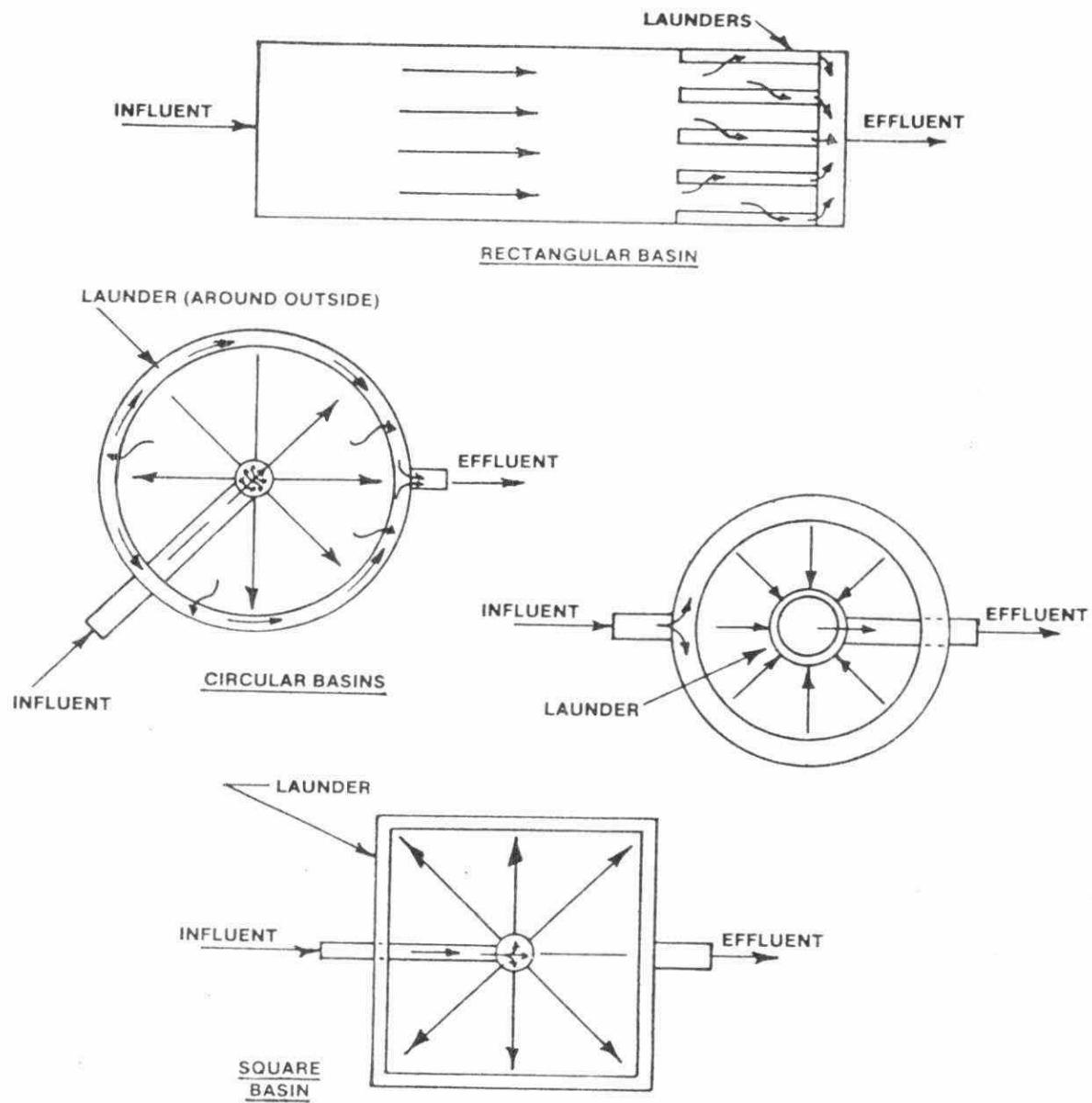


Figure 5-5 *Sedimentation basin types*

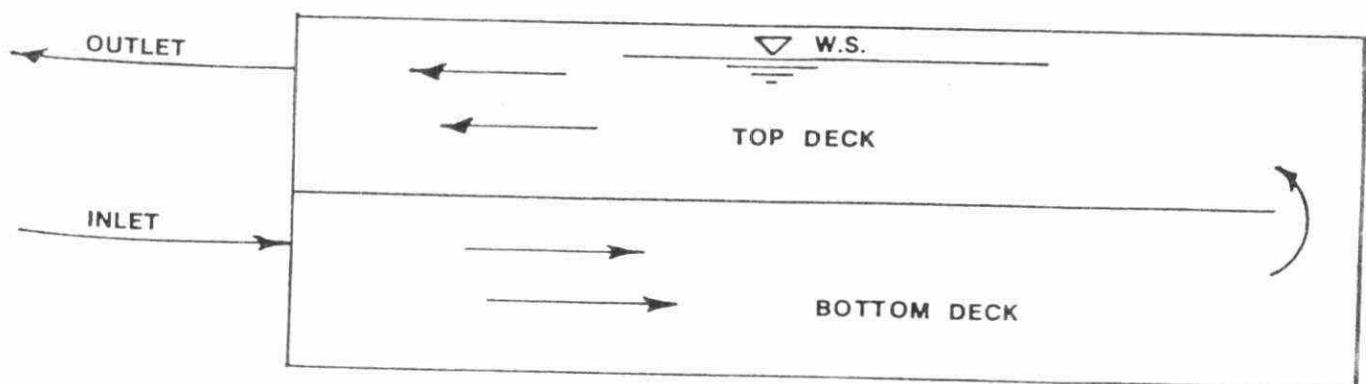


Figure 5-6 *Double-deck sedimentation basin (elevation)*

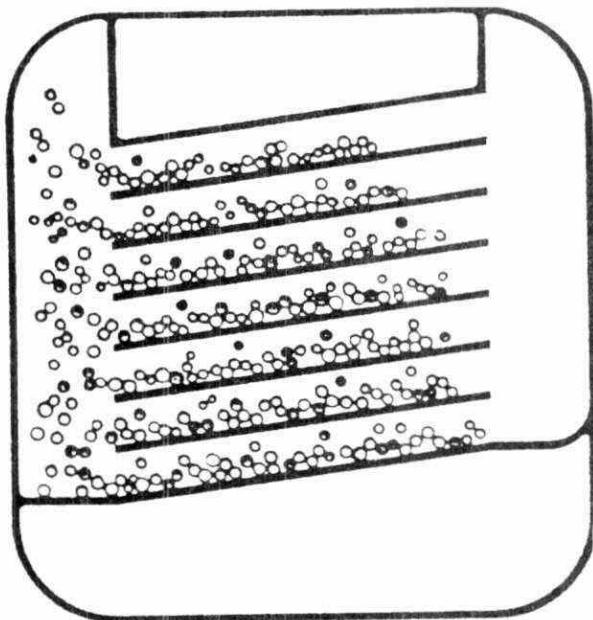
upward through the tubes as shown in Figure 5-7. Each tube functions as a shallow settling basin. Together they provide a high ratio of effective settling surface area, per unit volume of water. The settled particles can collect on the inside surfaces of the tubes or settle to the bottom of the sedimentation basin.

Parallel plate or tilted plate settlers can also be used to increase the efficiency of rectangular sedimentation basins, and these function in a manner similar to tube settlers.

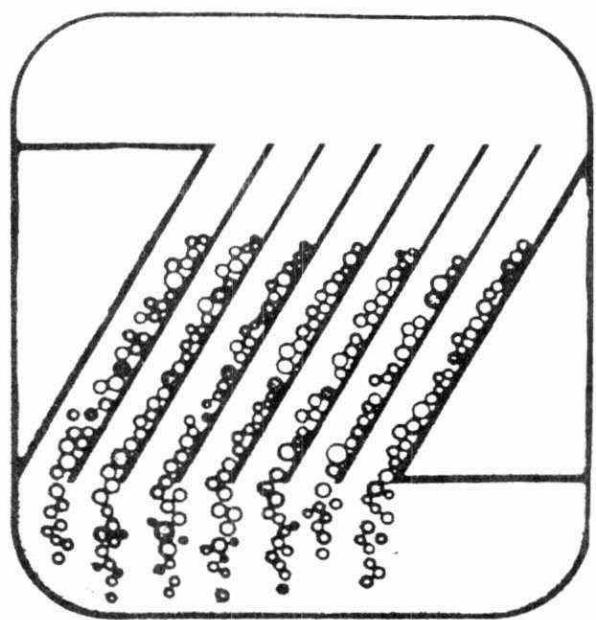
High-rate settlers are particularly useful for water treatment applications where site area is limited, in packaged-type water treatment units, and to increase the capacity of existing sedimentation basins. In existing rectangular and circular sedimentation basins, high-rate settler modules can be conveniently installed between the launders. High winds can have an adverse effect on tube settlers.

SUSPENDED SOLIDS CONTACT CLARIFIERS

The solids-contact process, also referred to as "up-flow solids-contact clarification" and "up-flow sludge-blanket clarification", was developed to improve the overall solids removal process under certain design conditions. These units combine the coagulation, flocculation and sedimentation processes into a single basin, which may be either rectangular or circular in shape. Flow is generally in an upward direction through a sludge blanket or slurry of flocculated, suspended solids as shown in (Figure 5-8).



7½° Tube Settlers



60° Tube Settlers

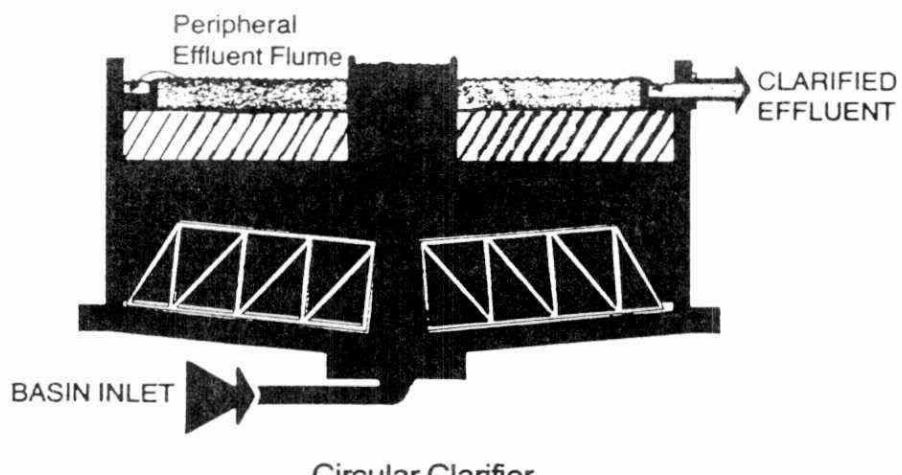
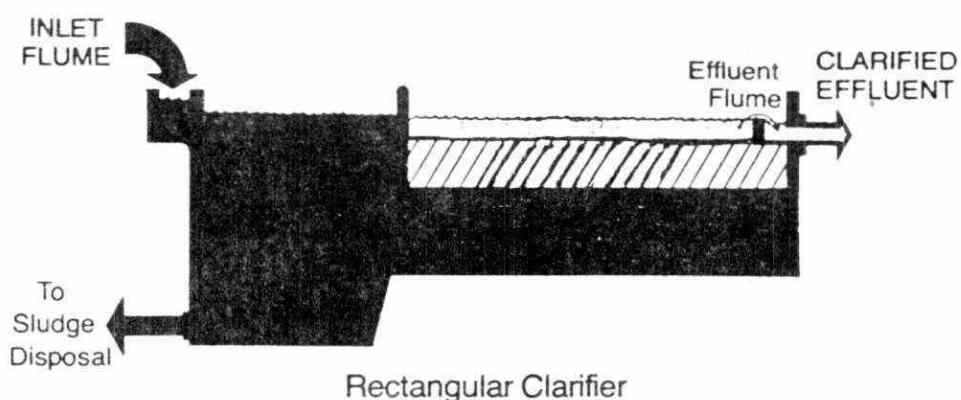


FIGURE 5-7 TUBE SETTLERS

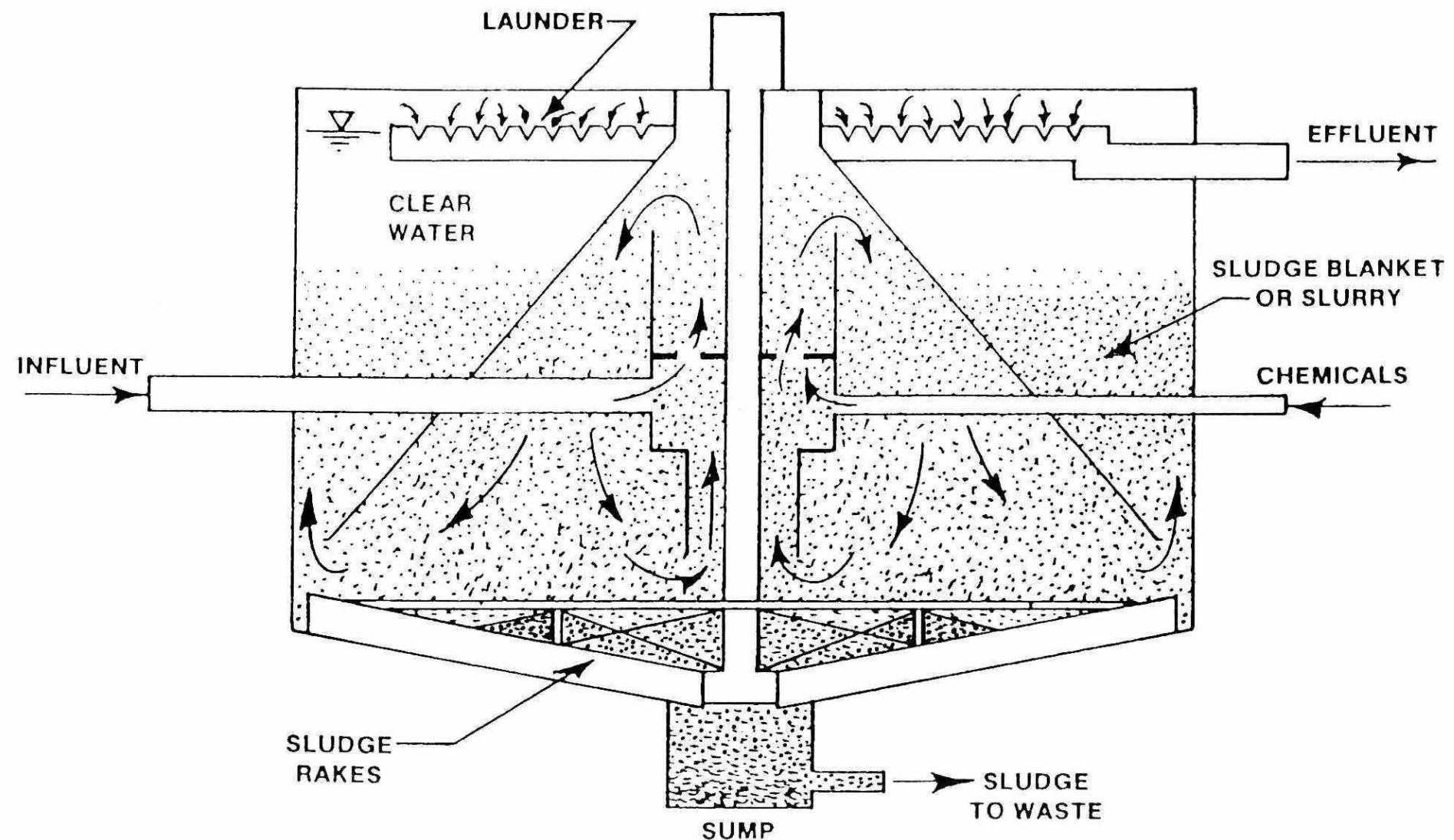


FIGURE 5-8 SUSPENDED SOLIDS CONTACT CLARIFIER

Solids-contact units generally have provisions to control removal of solids so that the concentration of solids retained in the basin can be maintained at some desired level.

Solids-contact units are popular for smaller packaged-type water treatment plants and also in cold climates where the units have to be inside a building. However, care must be exercised in the operation of these units to assure that a uniform sludge blanket is formed, and is subsequently maintained throughout the solids removal process. The sludge blanket is sensitive to changes in water temperature. Temperature density currents tend to upset the sludge blanket. Loss of the sludge blanket will affect the performance of the filters. Other important operational factors include control of chemical dosage, mixing of chemicals and control of the sludge blanket.

Under ideal conditions, solids-contact units provide better performance for both turbidity removal and softening processes requiring the precipitation of hardness. With softening processes, chemical requirements are usually lower also. In the case of turbidity removal, coagulant requirements are often higher. In either case, solids-contact units are very sensitive to changes in influent flow or temperature. In these facilities, changes in the rate of flow should be made infrequently, slowly and with great care.

SLUDGE HANDLING & REMOVAL

Water treatment plant sludges are typically alum sludges,

with solids concentrations varying from 0.25 to 10 percent when removal from the basin. In gravity flow sludge removal systems, the solids concentration should be limited to about 3 percent. If the sludge is to be pumped, solids concentrations as high as 10 percent can be readily transported.

In horizontal-flow sedimentation basins preceded by coagulation and flocculation, over 50 percent of the flow will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of operation of sludge removal equipment. Also you must consider the volume or amount of sludge to be removed and the sludge storage volume available in the basin.

Sludge which accumulates on the bottom of sedimentation basins must be periodically removed for the following reasons:

- 1) To prevent interference with the settling process such as resuspension of solids due to scouring
- 2) To prevent the sludge from becoming septic or providing an environment for the growth of microorganisms that can create taste and odour problems, and
- 3) To prevent excessive reduction of detention time.

In large-scale plants, sludge is normally removed on an

intermittent basis with the aid to mechanical sludge removal equipment. However, in smaller plants with low solids loading, manual sludge removal may prove to be the most cost effective.

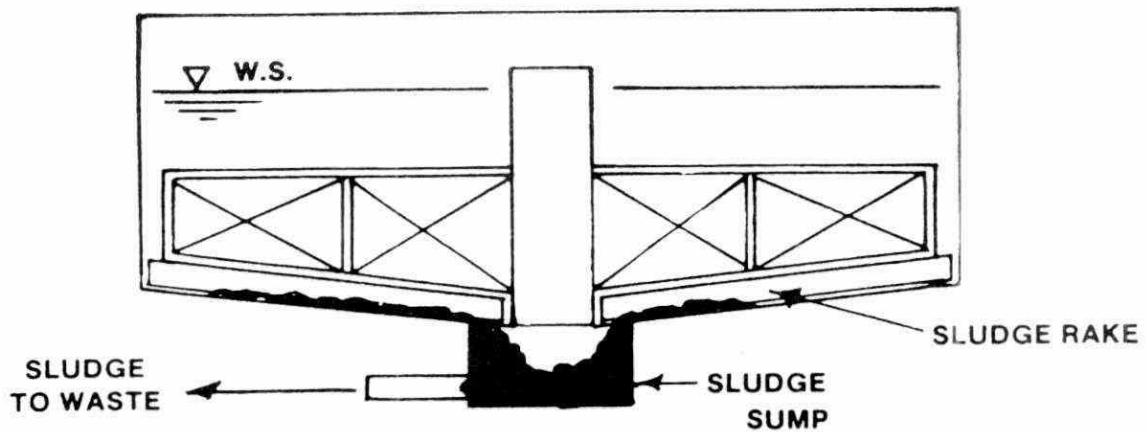
In manually cleaned basins, the sludge is allowed to accumulate until it reduces settled water quality. High levels of sludge reduce the detention time and floc carries over the filters. The basin is then dewatered most of the sludge is removed by stationary or portable pumps, and the remaining sludge is removed with squeegees and hoses. Basin floors are usually sloped towards a drain to help sludge removal. The frequency of shutdown for cleaning will vary from several months to a year or more, depending on amount of suspended matter in the raw water.

In larger plants, a variety of mechanical devices (Figure 5-9) can be used to remove sludge including:

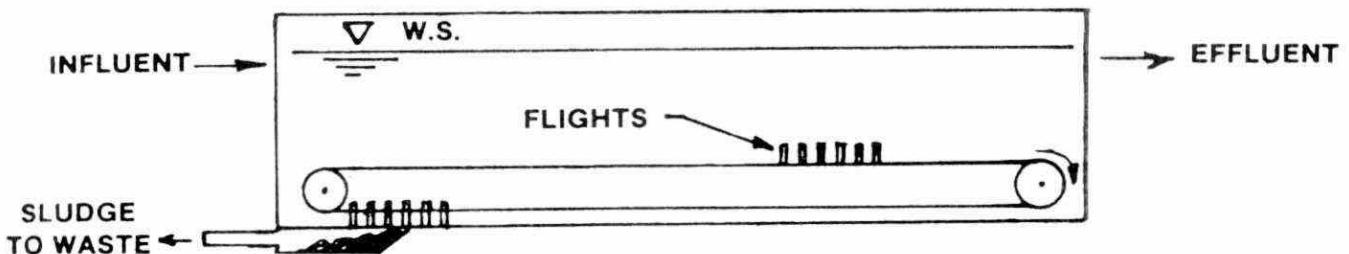
- 1) Mechanical rakes
- 2) Drag-chain and flights, and
- 3) Travelling bridges

Circular or square basins are usually equipped with rotating sludge rakes. Basin floors are sloped towards the center, and the sludge rakes progressively push the sludge towards a center outlet.

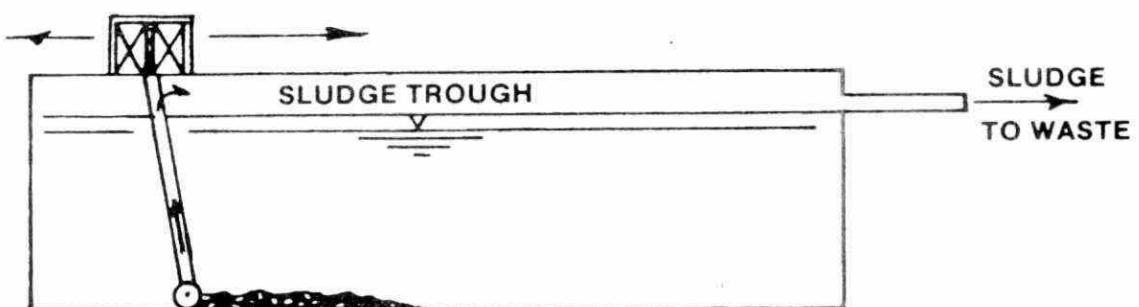
In rectangular basins, the simplest sludge removal mechanism is the chain and flight system. An endless chain outfitted with wooden flights pushes the sludge into a sump. The disadvantage of



MECHANICAL RAKES
(CIRCULAR OR SQUARE BASINS)



DRAG CHAIN AND FLIGHT
(RECTANGULAR BASINS)



TRAVELING BRIDGE — PUMP OR SIPHON
(RECTANGULAR BASINS)

FIGURE 5-9 SLUDGE REMOVAL

this system and of the rotating rakes previously described in high operation and maintenance costs. Most of the moving parts are submerged so the basin has to be dewatered to perform major maintenance.

In an attempt to reduce operation and maintenance costs and to improve sludge removal equipment maintainability, the travelling bridge was developed. This bridge looks like an old highway bridge except it has no deck for cars. The traveling bridge spans the width of the sedimentation basin and travels along the length of the basin walls. Moveable sludge sweeps, which are hung from the bridge structure, remove the sludge from the basin floor with suction pumps or by siphon action. There are few submerged parts in this system and these can normally be removed for maintenance without dewatering the basin. Traveling bridge sludge removal systems will operate effectively on the simplest of basin designs.

PROCESS CONTROL

The actual performance of sedimentation basins depends on the settling characteristics of the suspended particles and the flow rate through the sedimentation basins. To control the settling characteristics of the suspended particles, adjust the chemical coagulant dose and the coagulation-flocculation process. The flow rate through the sedimentation basin controls the efficiency of the process in removing suspended particles. The higher the flow rate, the lower the efficiency (the fewer suspended particles are

removed). Once the actual flow rate becomes greater than the design flow rate, you can expect an increase in suspended particles flowing over the V-notch weirs.

If adequate detention time and basin surface area are provided in the sedimentation basins, solids removal efficiencies greater than 95 per cent can be achieved. However, high sedimentation basin removal efficiencies may not always be the most cost-effective way to remove suspended solids.

In low turbidity source waters (less than 10 TU), effective coagulation, flocculation and filtration may produce a satisfactory filtered water without the need for sedimentation. In this case, the coagulation-flocculation process is operated to produce a highly filterable pin-point floc, which does not readily settle due to its small size. Instead, the pin-point floc is removed by the filters.

However, there is a practical limitation in applying this concept to higher turbidity conditions. If the filters become overloaded with suspended solids, they will quickly clog and need frequent backwashing. This can limit plant production and cause a degradation in filtered water quality.

From a practical standpoint, you will want to operate sedimentation basins near design flows. However, to achieve the intended removal of suspended particles once design flows are exceeded, suspended particles leaving the sedimentation basin may overload the filters with solids and require additional filter backwashing. Study the settling characteristics of the particles

by using laboratory jar tests. Then verify your test results and make adjustments based on actual performance of the water treatment plant.

During periods of low flow the use of all sedimentation basins may not be necessary. Since the cost to operate a basin is very low, it is recommended that all basins be kept in service except during periods of draining for maintenance and repairs.

SUBJECT:

WATER TREATMENT OPERATIONS

TOPIC:

Water Filtration

OBJECTIVES:

1. Recall the purpose of filtration;
2. Describe the filtration process;
3. In a rapid sand filter describe the purpose of different "layers";
4. Recall that the efficiency is determined by monitoring
 - a) loss of head
 - b) turbidity
 - c) rate of flow
5. Recall what is meant by:
 - a) filtration rates
 - b) backwashing
 - c) air wash systems
 - d) air/water scour;
6. Define and describe the operating problems of a filter;
7. Describe:
 - a) a "probe" check
 - b) how to check
 - i) "actual loss of head" across a filter
 - ii) "actual rate of flow" through a filter
8. Describe the differences between:
 - a) a pressure filter
 - b) a diatomaceous earth filter
 - c) a rapid sand filter.

PURPOSE OF FILTRATION

The primary purpose of filtration is to protect public health by removal of suspended material presented to the filter.

GENERAL CONSIDERATIONS

A prerequisite to filtration is proper pre-treatment. This may be accomplished by:

1. treating the "raw" water entering the plant with various chemicals,
2. mechanically agitating it for proper mixing and coagulation of the suspended matter to produce the desired floc, and
3. allowing enough retention time in the plant to settle out most of the suspended matter (in most plants).

The next and most important phase through which it passes is - FILTRATION.

Filtration is the process of removing turbidity (suspended particulate matter) from water by passing it through some porous filter media such as sand, anthrafilt or a combination of both.

FILTRATION PROCESS

Many years of Laboratory research and in situ operational observation have shown that the filtration process removes up to 95% of turbidity from the water presented to the filter. This is accomplished by Mechanical Straining, Impingement, Electrolytic Action and Chemical Reactions.

1. Mechanical Straining

The largest particles remain on top of the filter because their size will not allow them to pass through the small space between the individual grains of media.

2. Impingement

Did you ever wonder why it is that when you drive your car through mud in the pouring rain, that the mud splashed onto your car instead of washing off with the rain? This action is the same as when turbid water passes down through the sand grains in a filter. A natural attraction causes the particle to move to the surface of the media and stick to it.

3. Electrolytic

Both sand and anthracite grains carry an electrical charge as do to the particles of turbidity which are suspended in the water. The forces generated by the electrical charges cause the particles to cling together.

4. Chemical Reactions

There are many organisms in the top layer of the filter media. These organisms will promote chemical reactions with incoming turbidity and other organisms, affecting the filtering action.

THE "SLOW" SAND FILTER

Filtration, as we know it today, began in about 1830 when the first of the so-called "slow" sand filters was constructed and put into use in London, England. These units operated at rates of flow from 2 to 10 MGD per acre. (equivalent to 1/10 gpm per sq. ft.). The "slow" sand filter is

fast disappearing mainly because of the high cost of labour required to operate this type of unit, and the amount of the land required.

The "slow" sand filter consisted of an underdrain system with a gravel bed over it. On top of this was spread the filter sand. The water flowed in on top of the sand and filtered down through it, depositing the turbidity in the upper layers of the sand. During its passage through the sand layer the bacteria already present in the filter attacked and in most cases, destroyed any harmful bacteria present. The water was purified by this method rather than by chlorination. In fact, this was the only method of disinfection which was practiced at that time. Once the rate of flow became too slow for any further operation, the water was shut off, the unit drained, and the top layer of sand removed. The cost of removing the sand by hand and replacing it regularly was considerable.

THE "RAPID" SAND FILTER

The "slow" sand filter evolved into the "rapid" sand filter which is in use today. The "rapid" sand filter can either be of the gravity or the pressure type. In either case, the water passes through the bed of sand at rates of flow from 2 to 15 gpm per sq. ft., the higher rates generally are associated with deep bed anthracite filters. The water is usually pretreated by coagulation and settling to remove the greatest part of the suspended matter before the actual filtration process. At this higher rate relatively little purification took place by the bacterial method. (As more information became available regarding bacterial disinfection), chlorination was practiced to achieve disinfection. Unlike the "slow" sand filter, the "rapid" sand filter can be cleaned of the accumulated turbidity

by reversing the direction of the flow of water. This process is called *backwashing*.. In backwashing, the flow of water expands the sand, scours the bed and carries the accumulated solids to the sewer or waste treatment facility.

The media used in the "rapid" filter include *sand, crushed anthracite coal* and in some cases, a combination of these called *mixed media*.

DIRECT FILTRATION

Although we have been discussing filters that operate on water treatment by coagulation and sedimentation, in some installations this is neither necessary, nor practical. In many locations, the turbidity of the water is sufficiently low so that the filters can be operated without sedimentation. The alum is applied to the water through a mixer, followed by flocculation. All the turbidity, plus the coagulant which has been added, is applied directly to the filter. This is done to filters which contain either type dual or mixed media. This type of filter media has enough room to store the large amounts of solids applied to the filter and still get reasonably long runs. This type of filter is generally limited to those waters whose maximum turbidity will not exceed 40 TU and whose average turbidities are down in the range of 5 to 12 TU. Either gravity or pressure filters can be used.

CONSTRUCTION OF A SAND OR ANTHRACITE FILTER

A gravity filter is essentially a metal, fibreglass concrete box. Its length, width and depth are determined to suit the rate of flow which is desired. The depth of the box is determined by the amount of *head* or pressure required and also by the type of underdrain which is used.

The principal parts which make up a gravity filter are shown in (Figure 5-1) and include the *underdrain system*, the *gravel subfill*, the *filter media*, the *surface washer* and the *wash troughs*.

1. Underdrain System

The underdrain system collects the filtered water that passes through the media. The most common type of underdrain is the vitrified clay "LEOPOLD" drain tile. Holes on the upper side of the drain tile are properly sized to handle the water flows required for adequate water distribution during filtration and backwash operation. The backwash flow rate of the average filter is 12 to 15 gpm per sq. ft. and the operating rate only about 4 gpm per sq. ft. The only head available during the filtration process is the depth of water in the filter. Consequently the holes are sized to handle the filter flow. Adequate distribution of water is ensured at the higher flows encountered in backwashing due to the diffusing effect achieved by the flow and resultant loss of head through the underdrain systems.

2. Gravel Subfill

The subfill performs two primary functions:

- a) It supports the upper layers of sand and anthracite and separates them from the underdrain system,
- b) It distributes evenly the flow of water through the filter in both directions. (The depth of gravel required in design of filters is directly related to the distance between the holes and their size in the underdrain system).

Different layers, or size, of gravel make up the required depth. Progressively finer grades of gravel are spread on top of the coarse gravel; the minimum depth

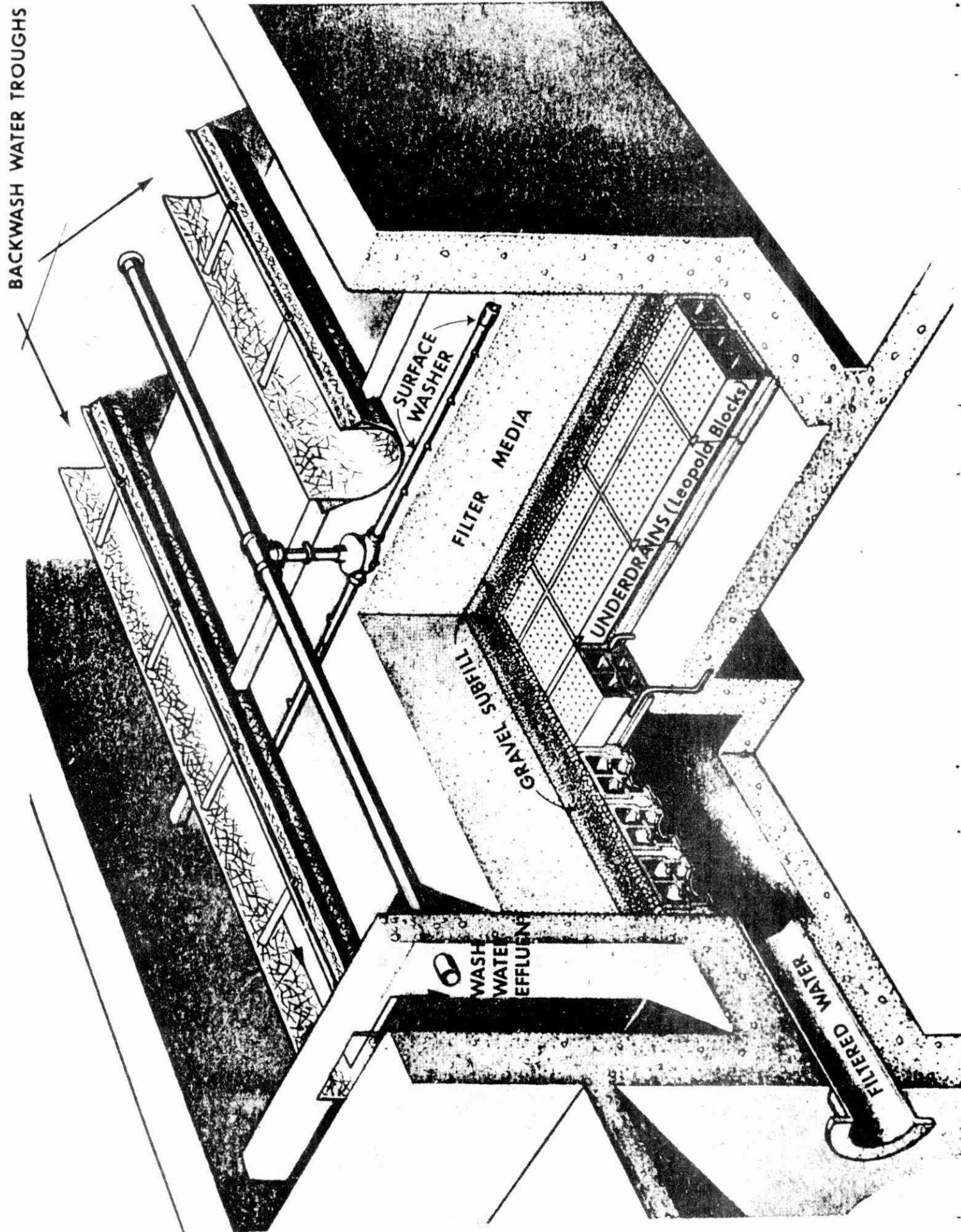


FIG. 6-1

CUTAWAY VIEW OF TYPICAL RAPID SAND FILTER

of a layer is 2" and the final layer of gravel, or "torpedo sand" as it is sometimes called, will support the actual filter media.

3. Filter Media

The actual filter media is on top of the gravel bed and varies in-depth up to approximately 6' deep. Today, with the advent of multi-media systems, garnet and other types of sand are used. These materials incorporate in the grain structure such things as carbon which greatly reduce their weight.

Anthracite, hard coal which has been crushed (screened) for size and graded to have a uniform density is the most widely used filter media. Crushed anthracite coal has a lower Specific Gravity (1.75) than sand (2.65); consequently, a lower velocity is required when backwashing the filter compared to that required to wash a sand filter of equal depth.

Crushed anthracite coal is lighter in weight (55 lbs. per cu. ft.) than sand (100 lbs. per cu. ft.); therefore, in order to benefit from both of these media, they are generally used together. They can be readily backwashed together and should always remain separated due to the difference in their specific gravities. The coarse anthracite on top gives the filter a larger capacity for turbidity removal. The combination of the two provides a media that will give longer filter runs with a resulting better quality of water. Recent designs utilize entire bed depths of anthracite for removal and storage of suspended matter.

4. Wash Water Troughs

The wash water troughs are located above the surface wash equipment. They are installed high enough above

the bed to provide a free space between the underside of the trough and the top of the bed equal to half the bed depth. This is the backwash space normally provided for the filter media to expand into for adequate cleaning without losing filter media. The depth of the wash troughs varies with the amount they can hold so the distance from the top of the wash trough to the top of the bed will range widely.

5. Other Necessary Accesories include the influent, effluent and wash water valves, and a valve to control the flow of water to the surface wash equipment. All of these valves are controlled from a console, usually located in front of and facing the filter. Built into the control console are gauges showing loss of head, rate of flow through the filter, backwash rate of flow, and effluent turbidity.

In some older plants, especially the smaller ones, individual hand valves are still in use. The large, newer plants feed data such as filter flow rate and loss of head into master control consoles which automate the valve operations required to backwash a filter and return it to service.

FILTER INSTRUMENTATION

To operate a filter at its full capacity and highest efficiency, the status of the filter is checked continuously and the *turbidity* (before and after filtration), *loss of head*, and the *rate of flow*, are recorded.

Turbidity

The prime function of a filter is to remove suspended matter thereby removing disease-producing organisms



Filter Control Gallery



Filter Control Console

from the water. Most of these organisms are bound up in the coagulated floc particles entering the filter. The turbidity remaining in the filter effluent is the best indicator of filter performance. Turbidities can be measured in the laboratory by such instruments as the Hellige or Hach turbidimeter, and can be monitored on the filters with indicating and/or recording type instruments such as those producing by Keen and by Hach manufacturers. Current regulations call for maximum turbidity in the plant effluent of 1.0 TU.

Loss of Head

A filter was earlier described as a box with an under-drain, gravel subfill and filter medium; the box, of course, is filled with water. In most large filters, the distance from the surface of the water to the centre of the underdrain system is approximately 10 feet. This is the total head or pressure available to push water through the filter. When the filter has just been backwashed, it is in its cleanest state and offers the least resistance to flow through it. This resistance or loss of head is the difference between the total depth and the initial loss, leaving an available head in most filters of about 8 feet (10 feet - 2 feet).

When in operation, the filter removes the turbiidity from the water. As the turbidity accumulates in the bed, the resistance to the flow of water increases; in other words, the available head through the filter decreases. Therefore, the reading of the loss-of-head gauge is an indication of the "cleanliness" or the "dirtiness" of the filter. The loss-of-head gauge indicates when the filter needs backwashing. A simple loss-of-head gauge can be constructed by connect-

ing a clear piece of plastic tubing to the under-drain header and running the tubing up to the side of the filter box so that the open end of the tubing is above the surface of the water in the filter. Mark the level of the surface water in the filter on the wall next to the tubing. Then, at any time, the distance from this point down to the liquid level in the tube can be measured - this distance (in feet) is the head loss. This is also a good method of cross checking loss-of-head instruments. Most modern loss-of-head instruments operate on this principle and simply transmit the measurement (or distance) to the instrument located on the control panel.

Rate of Flow

1. Constant Rate Filtration describes a flow through a filter which is maintained by the filter rate control valve independent of head loss. In other words, the required flow is set by the operator. The rate control valve then senses a decrease in flow which results from plugging of the filter bed (and increased head loss) and opens slightly to maintain the desired flow rate.
2. Declining Rate Filtration controls the filter operating head by raising or lowering the pressure in the filter discharge header. This action allows a clean filter to operate initially at a higher rate of flow per sq. ft. and then as head loss increases through the filter, a lower rate of flow is achieved per sq. ft. of filtering area.

This system has been shown to reduce terminal breakthroughs while increasing production some times up to 40% per day.

No significant difference was found in the quality of water produced by either control method.

FILTER OPERATION

Pre-Treatment

The most important thing to remember about the water arriving at the filter(s) is to condition and pretreat it thoroughly before it ever gets there. Without this pretreatment, (or if the pretreatment is inefficient) the operating efficiency of the filter(s) is going to be drastically reduced. Filter runs will be cut short, resulting in a considerable increase in backwashing and the amount of wash water used. Consequently, plant output will be reduced because filters have to be washed with filtered water. The filter beds will become overloaded with algae and particulate matter, and mud balls will very likely develop.

The type of conditioning applied to the raw water depends on the quality of the raw water entering the plant. The demand on water treatment plants, however, is continually increasing. If a given chemical treatment produces a good floc, coagulates well, and results in a water passing over the filter with, for example, turbidity of one (1) unit, at a flow rate of 25 MGD, an increase in flow rate to 40 MGD may not produce the same quality water over the filters even if the chemical dosage is increased in proportion to the increase in flow. This is

because increasing the flow rate by 60% will allow less time for the floc to settle out. This results in a greater "carry-over" to the filters, causing shorter filter runs.

Filtration Rates

Until a few years ago, the normal design filter rate for a rapid sand filter producing potable water, was 2 - 4 gpm per sq. ft. of filter bed area. Since then investigations of filter aids have been carried out, using dual and multi-media filters. As a result, operating filter rates are notably increased. It is common today to find filters operating at rates of 6 - 8 gpm per sq. ft. of filter bed area. These newly designed filters use a media in which the particle size is greatest at the top. By using various types of filter media, the particle size gets progressively finer, down through the bed to the bottom. Since the voids (or spaces) between the particles will be larger where the particle size is greatest, the voids in the upper portion of the bed are largest. These provide a greater storage area for turbidity particles. As the water proceeds through the bed, the size of these voids becomes progressively smaller due to the accumulation of turbidity particles. At the same time, the storage for the turbidity is becoming less, but the degree of filtration is becoming better.

It is common today to have up to five different layers of material in a filter bed. In other types of media, two layers are used, generally sand and crushed anthracite: two-layer filters are commonly known as dual media filters. The type of filter to be used is determined after a thorough study of the treatment process and raw water conditions.

It is sometimes possible to increase the flow rate through the filter. Filters are normally designed for specific rates of flow, and such things as the inlet flumes, the underdrain system, rate of flow controllers, and the discharge piping are all sized for this flow plus a factor of safety. Therefore, to double the rate of flow, the total head available in the filter may be sufficient to maintain this flow rate for short periods of time.

The conventional rapid sand filter uses one grade of sand (0.45 - 0.55 mm and a S.G. of 2.65) approximately 30 inches thick underlaid by graded layers of gravel as supporting media. Normally under these conditions, the actual entrapment of suspended matter is restricted to the top several inches of the sand bed. The remaining sand acts as insurance against a serious turbidity *breakthrough*, which means the turbidity on the filter has increased to the point where it is being carried through by the water being filtered.

The storing capacity for suspended matter in the conventional rapid sand filter is considerably less than in a dual-media filter where the top 18 inches of the sand bed have been replaced with a coarser and lighter media, such as a graded crushed anthracite (0.8 - 1.2 mm and a S.G. 1.75). Under ideal conditions, the entire 18 inch depth of anthracite plus 1-2 inches of sand, is available for the storage of suspended matter. This means that the head loss, instead of being concentrated in the top 2 inches in the conventional sand bed, is distributed through a depth of 18 - 20 inches in the dual-media bed. This makes it possible to use higher filter rates for longer filter runs.

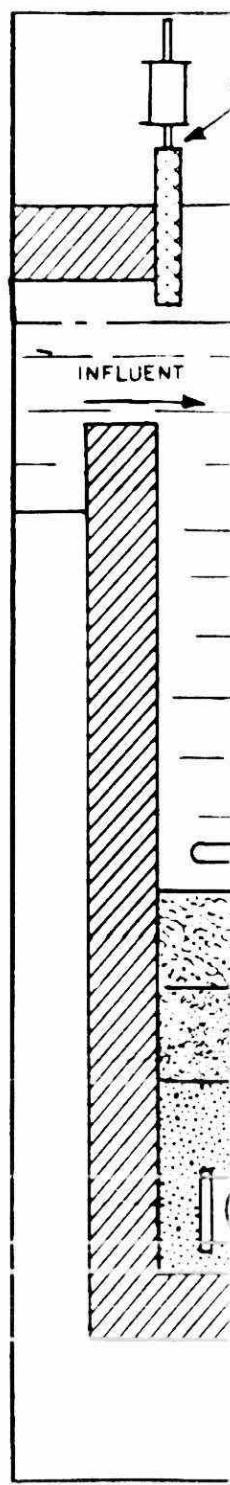
Backwashing (see Fig. 6-3, 6-4)

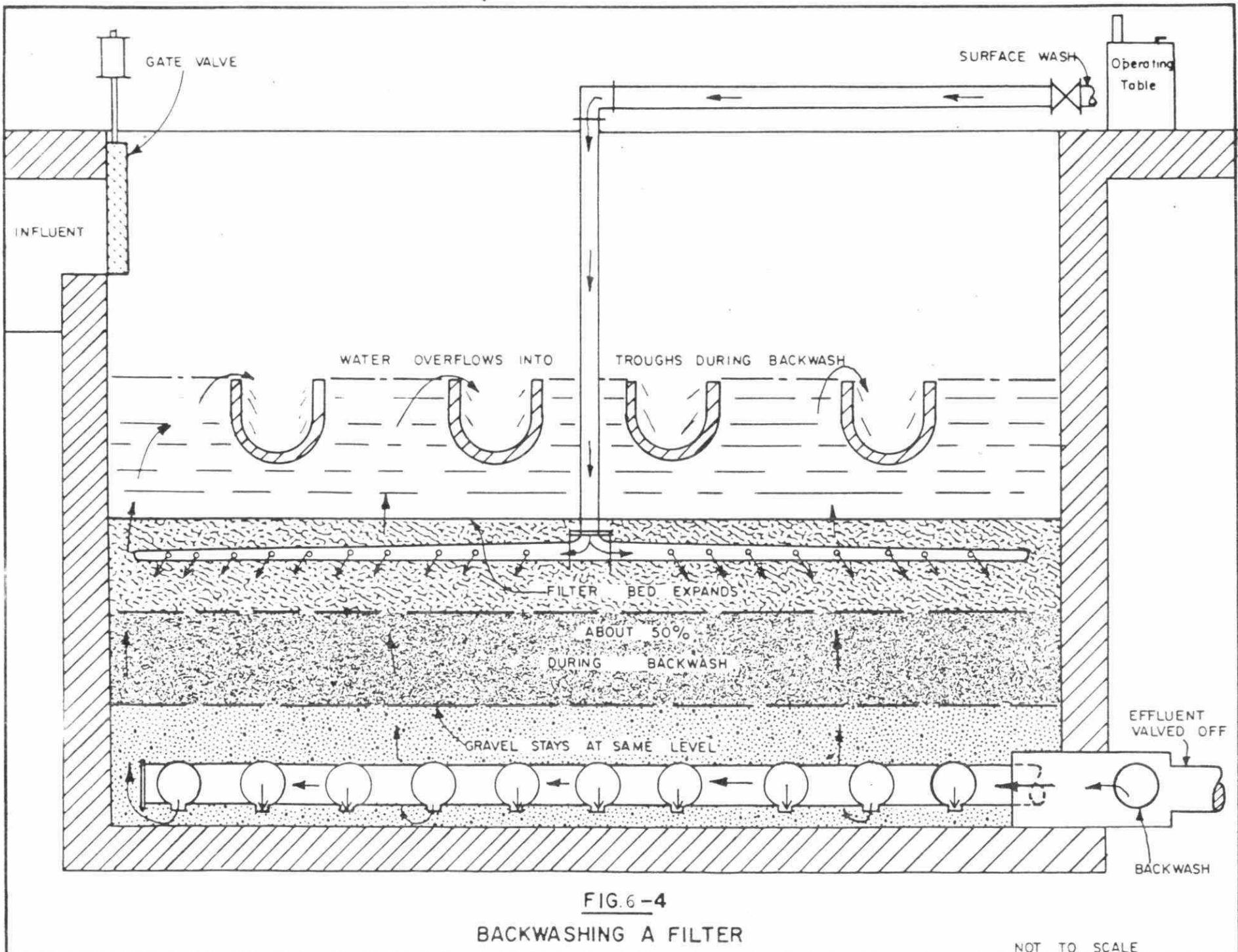
Backwashing a filter is the exact opposite to filtration. When backwashing, the water rises up through the filter rather than passing down through it. The backwashing

process removes the accumulated turbidity from the filter. Municipal filtration plants always utilize treated water for backwashing. The water is delivered to the filter either from an elevated tower or via a backwash pump (from the clearwell). Either method provides the necessary pressure and volume for carrying out the backwash process.

A normal rate of flow during the backwash cycle for conventional filters is 15 gpm per sq. ft. of filter bed area. These figures will vary depending on the temperature of the water used to backwash. As the temperature increases, the backwash rate is increased to give the same amount of expansion to the filter bed. The backwash water enters through the underdrain. Rising up through the gravel bed, it enters the filter media. The gravel bed further distributes the water uniformly throughout the entire filter. It is extremely important to note that *in the operation of any filter, all valves be opened or closed slowly*. As the backwash valve is opened, the amount of water rising up through the filter media gradually increases and as more and more water is forced up through the sand bed, the pressure on the underside of the individual grains of filter media becomes greater. This pressure eventually overcomes the weight of the particle of filter media and the point at which this occurs is known as *the point of fluidity*. Once the flow reaches this point, the particle will rise and the filter bed will start expanding. The normal expansion of the filter bed is 30 to 50 per cent during the backwash period. Backwash space must be provided in the filter to permit this expansion during the washing period. This is why the wash trough must be at a fixed height above the filter bed. The particles of media roll around in the bed, continuously rising and falling. In the process, they rub against each other. The combined action of the water moving past the particle of media and the

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scrubbing action of the particles rubbing against each other removes the accumulated turbidity from the filter media grains.

It was found from experience that this does not always remove all of the turbidity from the filter media, and that over the years, turbidity will accumulate on the media grains, limiting their effectiveness as a filter media. Superior backwashing may be achieved in the winter due to the denser water, however, a savings may be realized by reducing the backwash time because the bed is cleared faster.

Auxiliary Scour

Auxiliary scour better describes the function of this device as it aids in cleaning much more than the filter surface. Rotary surface washers are the most common, but fixed jets sometimes used as well.

The purpose of the surface wash is to aid in cleaning the filter surface and prevent mudball formation by applying a "jet" of water to the encrusted surface before and during wash cycles.

Initially the filter media is backwashed at about 6 gpm/sq. ft. (low rate). This is the point at which the particles of media are in effect "weightless" in the filter bed. The agitator is then turned on and allowed to run for a period of 5 to 7 minutes. The force of the jets of water from the agitator cleans the grains of the filter media and moves them so that the entire bed is gradually turned over and exposed to the jet action. Following this, the backwash rate is gradually increased and the agitator turned off. The filter is backwashed at its normal backwash rate for as long as economically necessary to remove all accumulated turbidity. The water is then slowly turned off and the media allowed to settle before returning the filter back to operation.

Air Scour Wash

Another method used to assist in cleaning the filter is accomplished by introducing compressed air into the backwash stream before it reaches the filter. Underdrain system for this type usually have smaller holes, thereby creating a very diffused air-water mixture. This mixture causes extensive agitation of the media as it passes through the bed. Many feel that the method is more efficient in achieving bed cleanliness than a standard backwash will permit.

Adequate backwashing in every filter operation is extremely important. *The backwash flow rate should be as high as possible without losing filter media.* The backwash should be carried on until the filter media is substantially cleaned. No media will ever be absolutely clean, regardless of the extent of the backwash.

OPERATING PROBLEMS OF A FILTER

The operating problems of a filter can be divided into two categories:

1. failure of the filter bed due to improper pre-treatment or operating procedures,
2. mechanical failure of controls and equipment.

Filter Bed Failure

When seeking the causes of filter bed failure, look for:

1. *Clogging* the filter media by turbidity accumulation. This is caused by incomplete removal during the backwash operation or inadequate pre-treatment.
2. "*Cracking*" or contraction of the bed. This results from too long a filter run or poor backwash techniques.
3. *Mud Balls* - Tiny balls of accumulated turbidity bind together with particles of filter media. As these

mud balls increase in size, they become heavier than the filter media and will gradually sink down to collect on the top layer of gravel.

4. The *shifting and intermixing* (sometimes called mounding) of the gravel layers - this problem occurs primarily in the fine gravels located in the top of the support bed. It is caused by uneven backwashing rapid change in flow rate, a clog or break in the underdrain system.
5. *Negative Head and Air Binding* - some filtration plants have only 4 to 5 feet of water above the media surface and air binding problems may occur occasionally. Air dissolves in water at or near the saturation point. When the pressure is reduced to less than atmospheric pressure below the surface of the media, air comes out of solution, and air bubbles accumulate within the media. This may result in a marked increase in the headloss. If the operator is not aware of this problem, media may be lost in the early part of the filter backwash due to the violent agitation of the air being released from the filter media. In most of Ontario's plants troubled by air binding, the problem occurs in the spring season when the surface water is in the stage of "warming up" and is supersaturated with air. To prevent loss of media, care should be taken at the beginning of the backwash to partially drain the filter below the overflow troughs prior to starting the backwash water pumps.

Checking the Filter

1. *Filter Peeker*-It is possible to look at gravel inside a filter to check for gravel mounding and also to check underdrains and to determine whether

or not mudballs are present. This can be achieved with the use of a filter peeker

A filter peeker consists of a hollow copper tube with a periscope type hood and handle at one end to look through and a rectangular shaped conical hood at the other end with a glass plate and small lights inside. Flashlight batteries at the end with the handles provide a light source. This practical gadget can be constructed by most water works operators.

The filter peeker is inserted into the filter during a backwash and moved by hand.

2. The maintenance of the filter bed itself involves a periodic "probe" check of the media to determine the contours of the pea gravel layer. This should be done twice a year.

To do a "probe" check, sketch an outline of the filter area. Drain the water from the filter to be checked. Walk along with wash troughs and thrust a six or seven foot length of steel rod down through the filter media until you feel the bottom of the rod come into contact with the pea gravel. Check a marker near the top of the rod against the lip of the wash trough to determine the depth of the gravel at that point. Enter the reading obtained by the "probe" at the appropriate point on the sketch of the filter area. Repeat over the whole bed to obtain an accurate picture of the gravel contour. If undue "humping" of gravel is found in any part of the filter, the sand anthracite must be removed from the area and the pea gravel re-graded and levelled.

3. *Bacterial Growth within the Filter Bed* - If prechlorination is not practised, trouble may be experienced with filter clogging due to bacteria growth within the bed. One effective method of cleaning up such a bed is by heavy chlorination, using one of the following methods:-

- a) Dosing the filter bed directly with a 12% hypochlorite solution
- b) Hooking up the plant chlorination facility to the backwash pump
- c) Hooking up a hypochlorinator to the backwash pump

Mechanical Failure of Filter Controls and Equipment

A good preventive maintenance program is essential to prevent mechanical failure of filter controls and equipment. This includes hydraulically or pneumatically operated gate valves, butterfly valves, sluice gates, rate of flow controllers, surface wash equipment, instruments for filter operation such as loss of head and rate of flow gauges, as well as the gauges used for indicating and recording the wash rates.

If you have a full and complete record of past troubles and breakdowns, including the repairs necessitated, a periodic review of such records will alert you to possible future trouble spots. Also, keep enough spare parts on hand to limit any downtime resulting from a breakdown of equipment and have the proper facilities and tools for repairs.

The filter console gauges, for loss of head and rate of flow, will provide continuous accurate readings only if they are given periodic calibration checks and maintained in good condition. No matter how sophisticated the instrumentation, the following checks should be made to determine their accuracy.

Instrument Checking and Maintenance

1. *To check the actual loss of head through any filter, obtain a length of polyethylene tubing, 1/4" or 3/8" diameter, pass one end down to the pipe gallery floor from the filter console above, connect the tubing to a centre tap on the filter effluent line and open the top allowing water to rise in tubing. The distance from the level of the water in the filter to the level of the water in the tube is the actual loss of head across the filter at that particular moment. If the indication on the filter gauge console does not agree with this value (plus or minus the allowable tolerance) the gauge reading is incorrect. Maintenance is required to correct the situation.*
2. *To check the actual rate of flow through the filter, use a "Hook Gauge". It is very accurate. A "Hook Gauge" consists mainly of a supporting member (1/8" x 1" scrap iron or similar) about 48" long to which are fastened two small brackets. On each bracket is positioned a 1/4" x 1-1/2" brass machine screw which has been ground to a needlepoint at one end. The pointed ends of the brass screws are held in the vertical position by the small brackets and lock nuts. These two "points" on the hook gauge can be positioned so that the distance between points is exactly six inches or 1 foot*

(whichever is preferred). A stop watch is used with the hook gauge. In use, the top end of the scrap iron is bent at right angles and the gauge is lowered into the filter, between any two wash troughs. To check the actual filter rate, close the filter influent valve leaving the effluent valve open. Watch the water dropping in the filter and when the water just "breaks" the top point of your gauge, start the stop watch.

3. The *operating cylinders* on the various *valves* (influent, effluent, wash and waste) need periodic checking to replace the gland packing and occasionally to replace the cup leathers on the piston.
4. The *surface wash equipment* requires little maintenance except for occasional cleaning of the jets on the agitator arms. If the filter media is anthracite some fine grains may become lodged in the jets but it is a simple matter to unscrew these for cleaning. *Even though this is a minor maintenance chore, it should be done periodically, because the agitator arms will not perform effectively if a number of jets become clogged.* The ball bearings on which the agitator arm rotates give very little trouble, but should be part of the regular P.M. programs.

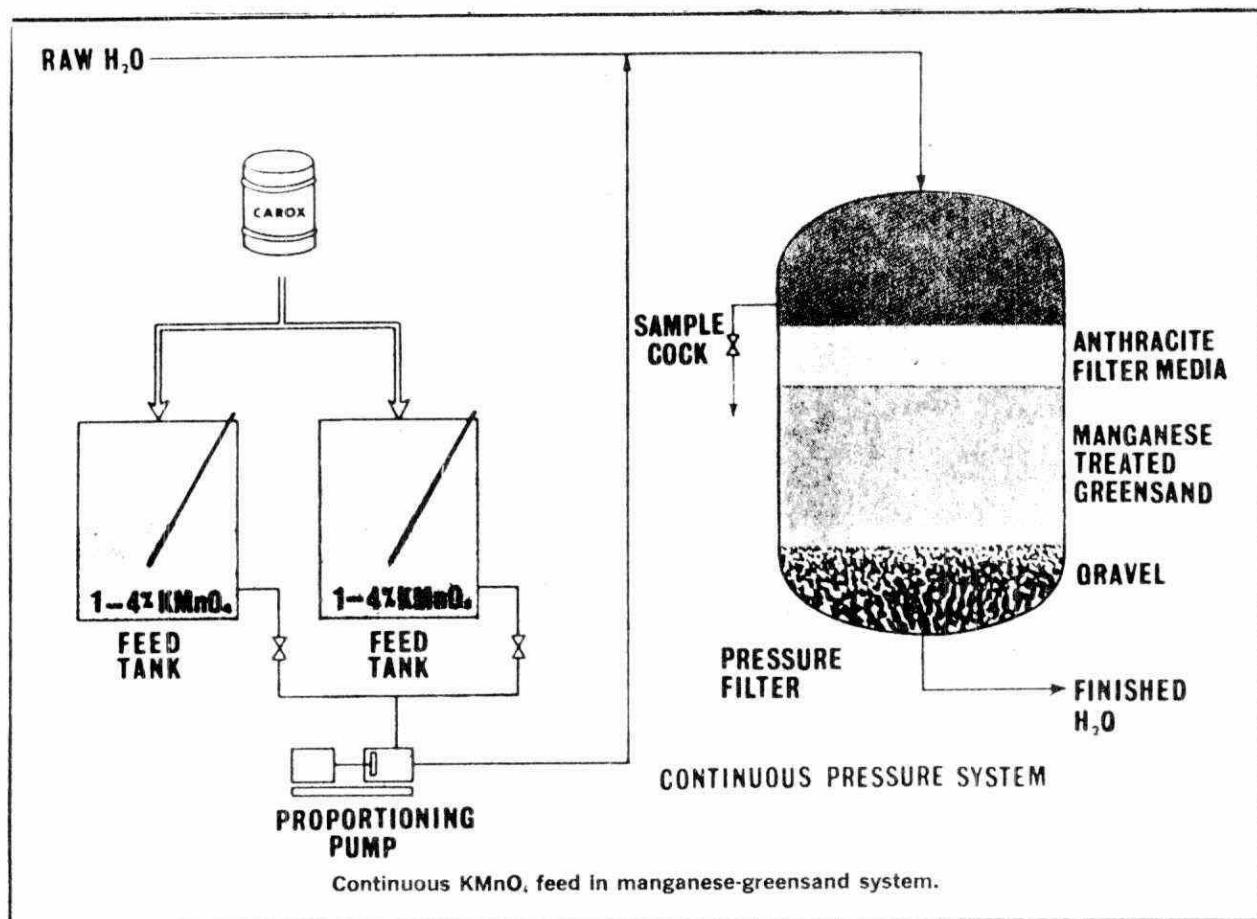


Figure 6-5 Pressure Filter

Stop the watch exactly at the point where the dropping water just "breaks" the bottom "point" of the gauge. The time taken for the filter to pass either 6" or one foot of water in a given period is determined accurately. Knowing the filter area, the rate can be calcualted in millions of gallons per day (MGD), which is indicated on the console instrument. A very accurate check is obtained on another aspect of the filter, because a given volume of water passing through the filter in a given time is measured and determined. Allowances must be made for the space occupied within the filter by such accessories as wash water troughs and gully walls, and whether the time is checked with the water level above the troughs or below them.

PRESSURE FILTERS (see Figure 6-5)

There is relatively little difference in the design of gravity and pressure filters as far as the internal components are concerned. There is one very large difference in their OPERATION. A gravity filter only has a pressure of approximately 8 feet of water on it; the pressure across the bed of a normal pressure filter can be as high as 60-70 psi. It is therefore possible to "drive" or "push" the water through these filters.

Since it is generally not feasible to provide large vessels equivalent to the capacity of the flocculation and sedimentation chambers of a conventional plant, it therefore becomes quite difficult to provide both adequate settling and transfer of water from the effluent of the settling basin to the filters. This transfer, in the case of a pressure filter, requires more vigorous pumping rates at a higher pressure

than on a rapid sand filter. The pumping process would cause a break up of the floc particles resulting in a much deeper penetration of the filter and less filter efficiency. The in-line application of coagulant such as alum is generally not satisfactory, and lends itself to only a very limited number of water sources to be treated. Coagulant aids (polyelectrolytes) are a great help when applied to pressure filters, as they can be used for in-line application. Application is achieved by use of an in-line flash mixing device and a subsequent rapid floc formation results.

Since the sand bed cannot be seen during the backwash period (and this is one of the main disadvantages of such a unit from the operator's viewpoint) the best procedure is to provide a sample stream which can be examined continuously during the backwash and ensure that the rate of flow will not backwash the filter media out of the unit. From time to time, however, it is necessary to increase the backwash rate to a point where a small amount of media is being lost. This determines that the unit is being backwashed at the maximum possible rate. All these difficulties can be overcome through the installation of proper controls, so pressure filters of either the vertical or the horizontal type can be used to good advantage in small installations where gravity filters are too costly.

DIATOMACEOUS EARTH FILTER

Diatomaceous earth filters can be described as filters in which the filtering media is discarded along with the accumulation turbidity. Diatomaceous earth is a natural occurring material composed of the fossilized skelton remains of microscopic algae known as diatoms. Each tiny diatom is a very porous structure of almost pure silica and therefore makes an ideal filter media. There are a few diatomaceous earth filters installed in the Province for the treatment of water. These filters are generally limited to those waters

which have little turbidity. The filters themselves are either of the pressure or the vacuum type; in either case, the water is clarified by passing it through the diatomaceous earth. Diatomaceous earth is held on a fine mesh fabric or screen (called septum) by the pressure of the water passing through it. Diatomaceous earth removes the turbidity from the water by filtration. Turbidity accumulates in the coating or "cake".

In the operation of the filter, a small amount of the earth is circulated through the filter and accumulated on the septum, building up a thick cake known as a PRE-COAT. The raw water is then fed to the filter. A small amount of additional diatomaceous earth is mixed with the water. This added portion is known as the BODY FEED. There is a continuous accumulation on the septum consisting of a mixture of turbidity and diatomaceous earth. Since diatomaceous earth is by nature porous, the rate of pressure build-up can be controlled by varying the amount of body feed as required. The limit of filtration is governed by the pressure loss across the filter; a pressure loss of 30 psi across the filter is not uncommon in pressurized systems. When the maximum allowable pressure has been reached, the direction of water flow is reversed and the accumulated diatomaceous earth and turbidity is flushed to the drain. A new pre-coat is installed on the septum and the filter is ready for a new cycle. Like the pressure filters, this type of system has only proved competitive from a cost standpoint on the small systems.

SUBJECT:

TOPIC: 7

WATER TREATMENT OPERATION

Chlorination

OBJECTIVES:

The trainee will be able to:

1. Recall the purposes of chlorination;
2. Recall the purpose of MOE Bulletin 65-W-4;
3. Recall the criteria for chlorination equipment required in a water treatment plant; (See Bulletin 65-W-4)
4. Recall routine operation to follow in chlorination (See Bulletin 65-W-4);
5. Determine the procedures for Emergency Operation;
6. Determine the procedures that may be required if adverse results are obtained from bacteriological samples.

CHLORINATION

PURPOSE

Chlorination may be performed at a water or wastewater treatment plant for many purposes but the most important is *disinfection* of the plant effluent. When effluents are discharged to bodies of water or water distribution systems, treatment for the destruction of bacteria and viruses is required to minimize the health hazards. Such treatment is known as *disinfection*. The amount of chlorine necessary to obtain a satisfactory reduction of bacteria will vary greatly with the composition of the influent and/or the degree of treatment the plant provides. The selection of the appropriate disinfection procedures is based on the results of bacteriological tests and other evaluations of the total system.

PROPERTIES OF CHLORINE

Chlorine is a greenish-yellow gas with a penetrating and characteristic odour. It is $2\frac{1}{2}$ times heavier than air, and one volume of liquid chlorine equals 450 volumes of chlorine gas. It can be compressed into a liquid which has a clear, amber colour. At -35°C it has zero vapour pressure. However, as the temperature rises so does the vapour pressure and at 20°C it is 82 psi gauge pressure. This characteristic has to be considered when

1. feeding chlorine gas from a cylinder,
2. dealing with a leaking cylinder.

Chlorine has a high coefficient of expansion. For example, a temperature rise of 25°C (from -5°C to 20°C) will increase the volume by approximately 85 per cent. Such an expansion could easily rupture a cylinder or line if it is full of liquid chlorine. This is the reason for the regulation that all chlorine containers must not be filled to more than 85% of their volume.

Chlorine by itself is non-flammable and non-explosive, but it will support combustion.

TABLE 7 -1

<u>PROPERTIES OF CHLORINE</u>
Greenish-Yellow Colour
Heavier than Air
High Rate of Expansion
Moderately Soluble in Water
Non-Flammable and Non-Explosive
Supports Combustion at High Temperature

Chlorine does not kill bacteria and viruses directly but, when chlorine gas and water are mixed together in the chlorinator, hypochlorous acid, a strong oxidizing or disinfecting agent is formed.

Chlorine is a surface-active agent and there is a reasonable chance that bacteria hidden within solid particles will not be killed by chlorine. For this reason, chlorine is added for disinfection purposes at a point after solids removal. In water treatment, turbidity removal is important because bacteria can be concealed within the turbidity particles and be inaccessible to the effects of chlorination.

REACTION OF CHLORINE

Chlorine is an extremely active chemical that will react with many compounds to produce many different products. Such reactions complicate the disinfection process because the chlorine demand of these materials must be satisfied as well as those associated with the disinfection reactions. The quantity of both organic and inorganic substances in the influent varies from place to

place and from time to time, so the amount of chlorine to be added will also vary. Sufficient time (contact time) must be allowed so that there is complete reaction of the chlorine with the chemical and bacterial pollutants as chlorine is added to water or wastewater. The reactions proceed generally as follows:

1. If chlorine is added, it will first react rapidly with reducing compounds such as hydrogen sulphide and ferrous iron. No disinfection results.
2. As more chlorine enters solution, it will react with the organic matter present to form chloro-organic compounds, which will have a slight disinfecting action.
3. Chlorine added in excess of that required by Steps 1 and 2 will react with ammonia and other nitrogenous compounds to produce *chloramines*.

The chlorine used by these organic and inorganic substances (Steps 1 and 2) is known as the chlorine demand.

The chlorine used by ammonia and the nitrogenous compounds is known as the combined residual (Step 3).

The combined residual (chloramines) has a disinfection capability but is slow acting and requires a long retention time. To reduce retention time and increase disinfection efficiency, chlorine in excess of that required in Steps 1, 2, and 3 above can be added. This will destroy most of the chloramines (Step 3) depending on the amount added. If chlorine is in excess of that required to destroy the chloramines, it forms hypochlorous acid or hypochlorite ions. This is known as free residual chlorine.

Total Residual Chlorine is combined residual plus free residual.

Chlorine dosage is chlorine demand plus total residual chlorine.

Combined vs. Free Residual

Whether combined or free residual chlorination is practiced depends on a number of considerations.

1. Combined residual chlorine is the method of choice when
 - a) long contact time is afforded
 - b) high and enduring residuals are desirable
 - c) control of algae, aftergrowths and red water in the distribution system is necessary
 - d) chlorine taste and odour must be prevented or minimized.
2. Free residual chlorine is the method of choice when
 - a) water quality is poor
 - b) short contact times exist
 - c) there are high concentrations of iron, manganese and colour
 - d) difficult tastes and odours must be minimized.

In Summary:

The amount and type of chlorine residual used is controlled by:

1. *degree of chemical and bacterial pollution,*
2. *contact time in the plant beginning with the application of chlorine until the amount reaches the first consumer or receiving body of water. For effective disinfection, always add chlorine at a point where complete mixing will occur. A minimum contact time of 15 minutes is recommended.*

OTHER USES OF CHLORINATION

While the principal purpose for chlorinating water supplies is disinfection, it serves other purposes:

1. Control of taste and odour problems when free or combined residual chlorination is practised. If too little chlorine is added, the taste and odour problems may become severe.
2. Oxidation of manganese, nitrites, and ammonia, or the destruction of phenols and the removal of algae and slime growth.

CHLORINATION OBJECTIVES

The Ministry of the Environment (Bulletin 65-W-4) has set minimum objectives to be used by treatment plants for chlorination of public water supplies. These objectives are set up on the broadest concept to protect the maximum number of consumers at any one time. Occasionally these minimum objectives will have to be EXCEEDED in water plant operating practice and a higher residual may have to be used. A copy of the Bulletin is at Appendix 1.

An operator can follow the guidelines in meeting the minimum objectives, but still produce a water contaminated with coliform bacteria. In these cases, public health is in danger. Immediate changes in the chlorination program must be made, such as:

1. increase the chlorine residual,
2. change the type of residual,
3. change the point or points of application,
4. increase the contact time between point of application and the first consumer.

The water utility is an industry and certain quality control measures are required. One of these is the chlorine residual analyser and recorder. This equipment must be kept in proper operating order. The record of chlorine residual provides the operator with positive proof of the degree of performance.

The chlorine residual must be checked and recorded at least once every 8-hour shift. The residual is always maintained at or above the minimum required for the plant. See Para. 3.1 of Appendix 1 for recommended chlorine residuals.

pH AND ITS EFFECT ON CHLORINATION

The pH of a water is an indication of its acidity or alkalinity. It can be lowered to corrosive levels by the addition of chlorine, alum and other coagulants. In some cases, the pH of the raw water may already be too low. Regardless of the cause of low pH, it should be corrected to prevent corrosion by adding an appropriate alkali before the water goes to the distribution system. *All chlorine compounds are most effective in bacteria and virus destruction at low pH. Any pH correction upwards (above 7.5) should be done after the chlorine has done its work.*

IMPORTANCE OF TURBIDITY REMOVAL IN WATER TREATMENT

In the chlorination of water, no mention is made of the effects of turbidity because it is assumed that the water meets the turbidity requirements of 1 unit maximum. However, bacteria can be concealed within the turbidity particles and be immune to the effects of chlorination. Turbidity removal improves the appearance or clarity of the water and prevents the accumulation of mud in the distribution system. However, turbidity removal is also very important because it eliminates "chance bacteria contamination" as well.

CHLORINE RESIDUAL DETERMINATION

Common methods for determining chlorine residual in water are:

1. DPD Method (Palin)
2. Spectrophotometer
3. Amperometric Titration

The test procedures for these methods are detailed in Topic 14.

DPD (Palin) Method

The DPD method is judged the best colorimetric method for free chlorine in water.

Both free and combined chlorine residual can be analyzed by this method. Differentiation between the free and combined forms of chlorine residual simplify the control of modern chlorination processes.

Spectrophotometer Method

The spectrophotometer measures concentrations of particular substances in water by the colorimetric method. It gives a high degree of accuracy for the measurement of free and total chlorine residual.

Amperometric Titration Method

The most accurate method of measuring free and combined chlorine residuals is by the Amperometric titration procedure. This method uses an electric current measuring device to indicate when the chlorine or chlorine indicator has been removed by a titration process.

Phenylarsene oxide is the reducing agent normally used as the titrating agent. It reacts with free chlorine residuals at pH 6.5 to 7.5 in a quantitative manner.

By conducting a two-stage titration with the pH adjusted at about 7 and then at about 4, free and combined chlorine residuals can be measured separately. Interference from nitrites and oxidized forms of manganese are eliminated by conducting the titrations at pH level above 3.5.

APPENDIX I

CHLORINATION OF POTABLE WATER
SUPPLIES

Ontario Ministry of the Environment

BULLETIN 65-W-4

Revised March, 1980

CHLORINATION OF POTABLE WATER SUPPLIES

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Ontario Ministry of the Environment

Bulletin

CHLORINATION OF POTABLE WATER SUPPLIES

1.0 Introduction

1.1 Purpose of Bulletin

Disinfection, to kill pathogenic organisms, is the most important step in any water treatment process. In Ontario it is usually accomplished by adding chlorine. This chemical has many other uses in water treatment such as coagulation aid, taste and odour control and maintenance of water quality in the distribution system, but its primary purpose is disinfection. This bulletin outlines the requirements to achieve adequate disinfection and the procedures to follow when it is not achieved. The bulletin also outlines a design standard. New installations should meet the criteria as set out in the bulletin and existing facilities should be brought up to these standards.

1.2 When is Disinfection Required?

Continuous and adequate disinfection is required when the supply is obtained from a surface source; when ground water sources are or may become contaminated, as in fractured limestone areas; when the supply is exposed to contamination during treatment or when emergency conditions such as flooding or epidemic, indicate the need. Disinfection equipment should also be available at those plants where continuous disinfection is not required, to allow temporary disinfection if unsatisfactory or poor bacteriological quality of water is reported. The design of all plants should incorporate suitable connections for disinfecting equipment to be added for this purpose.

1.3 Types of Chlorination

Chlorine when added to water immediately dissociates into hypochlorous acid and hydrochloric acid. The former compound can

further dissociate to hypochlorite ion and hydrogen. Hypochlorous acid predominates when the pH is below 7.5. It is the compound that is the prime disinfecting agent in a free chlorine residual. However it is very reactive and will quickly combine with certain compounds (eg. ammonia) and slowly with many other compounds, that may be present in water, to produce a combined chlorine residual (monochloramine, dichloramine etc.). When sufficient chlorine is present so that the reactions that form the combined chlorine are completed, the breakpoint has been reached. The addition of more chlorine will then yield a free chlorine residual.

Of the many regimes of chlorination, simple or marginal chlorination is probably the most common. This is also probably the least effective, especially if it is the only treatment applied to surface water. Chlorine is applied to give an initial total chlorine residual of 0.2 - 0.5 mg/L, predominantly as a combined residual that frequently disappears in the distribution system.

Free residual chlorination produces a much superior disinfecting agent. Sufficient chlorine should be added so that the free residual comprises about 60 to 80 percent of the total residual and it should be maintained through all of the water treatment plant and distribution system. Very high free residuals (super-chlorination) would necessitate at least partial dechlorination, before entering the distribution system, with sulphur dioxide, sodium thiosulphate or activated carbon. The addition of ammonia will produce the more stable but less active disinfectant, chloramine.

If only a chloramine residual is desired, it can be achieved by adding ammonia before the chlorine. However a much higher dose and/or much longer contact time is required to achieve the same degree of disinfection as a free chlorine residual.

Pre-chlorination together with post-chlorination, as required is a frequent mode of operation at Ontario water treatment plants. If organic compounds in the raw water tend to cause formation of chlorinated organics (chloroform, etc) it may be advisable and possible to chlorinate just prior to or after filtration when many organic

precursors may have been removed. However, the bacteriological integrity of the water must receive first priority when considering any modification to chlorination practices aimed at reducing the formation of chloro-organics.

2.0 Equipment

Chlorination equipment must be readily available at all water treatment plants. This includes all ground water supplies where chlorination is not continuous.

2.1 Capacity

Chlorination equipment shall have a maximum feed capacity at least 50% greater than the highest expected dosage required to provide a free chlorine residual of 1.0 mg/L in the finished water.

2.2 Duplicate Equipment

Chlorine feed equipment (both gas and hypochlorite chlorinators) at waterworks where disinfection is required, shall be installed in duplicate, to provide uninterrupted chlorination in the event of a breakdown. In addition, spare parts consisting of at least the commonly expendable parts such as glassware, rubber fittings, hose clamps and gaskets, should be provided for effecting emergency repairs.

For a multi-well supply system requiring chlorination for disinfection the standby requirements may be met by one portable unit.

2.3 Chlorinators and Controls

Dependable feed equipment, either of the gas feed or positive displacement solution feed type, shall be used for adding chlorine. Automatic proportioning of the chlorine dosage to the rate of flow of water should be provided at all plants, especially where the rate of flow varies without manual adjustment, or operation of valves and/or switches. Where the chlorine demand is not constant, it may also be necessary to either adjust the chlorine dose through

a chlorine residual analyzer, or feed a constant chlorine dose and use the chlorine residual analyzer to regulate the feed of a dechlorinating agent.

2.4 Gas Chlorination

2.4.1 Building Design

Gas chlorine equipment - (chlorinators, weigh scales, chlorine cylinders) must be located in an isolated room or rooms. In larger installations the storage and weighing facilities should be in a room separate from the chlorinators. The construction of the facility should be of fire-resistant and corrosion proof material, have concrete floors and be gas tight. All interior surfaces should be coated with a substance impermeable to chlorine gas.

A set of corrosion resistant scales should be available for weighing the chlorine cylinders. Scales for 69 kgm (150 lb.) cylinders should be of the low profile type. Non-low profile scales shall be recessed in the floor. Safety chains shall be used to retain each cylinder, in storage and on weigh scales, in a safe upright position.

Chlorine should not be stored below ground level and the cylinders must be protected from excessive heat, dampness and mechanical damage. One ton cylinders shall be stored on their sides on level racks.

Where rail cars are used, a dead end siding restricted to chlorine tank cars shall be provided. The tracks must be level and protected by a locked derail or a locked closed switch.

Areas containing chlorine or chlorination equipment shall be clearly marked "Danger! Chlorine Storage" or "Danger! Chlorine Feed Equipment" as applicable. The exit doors with "panic" hardware shall be hinged to open outwardly. There shall be two or more exits if the distance to travel to the nearest exit exceeds 15 feet. All exits from the chlorine room and storage area should be to an outside wall. Access between these rooms is permitted if they have a common wall.

The temperature in the chlorine storage and scale room shall not be higher, and preferably slightly lower than that in the chlorinator room. The gas lines between the scales, chlorinators and injectors shall not be located directly on an outside wall or in a location where low temperatures may be encountered.

2.4.2 Safety Equipment

Each plant shall have readily available, a self-contained or air-supplied respirator of the pressure demand type. One respirator shall be located in a conspicuous location outside the area of probable contamination.

Protective clothing including gloves, goggles and safety shoes shall be available for persons handling chlorine.

Eye wash fountains shall be located as near as possible but outside the area of probable contamination.

All chlorine rooms must have a chlorine leak detector alarm system.

Container emergency kits to repair leaking valves, fusible plugs or the tanks themselves are available from chlorine suppliers. There are different kits for each size of tank and the proper size should be available at each water plant.

2.5 Hypochlorite Chlorination

It is important that hypochlorite compounds which contain an algicide not be used as a disinfecting agent in potable water systems.

2.5.1 Safety Procedures

Sodium hypochlorite (a liquid) and calcium hypochlorite (a powder) are frequently used to provide chlorination at small municipal water plants and to disinfect mains and reservoirs. Certain safety precautions must be observed in the storage and handling of these compounds.

Calcium Hypochlorite

Certain precautions must be taken when adding granular calcium hypochlorite.

- 1) Store containers in a clean, cool, dry area away from any combustible material. Spontaneous combustion can result from improper storage. Keep the containers away from moisture, heat and fire. There should be no smoking in this area.
- 2) Metal drums should be kept upright and should not be dropped, rolled or skidded. Calcium hypochlorite, if dropped, can explode and burn.
- 3) Empty containers should be thoroughly rinsed with water.
- 4) When handling calcium hypochlorite it must never have contact with the eyes and it can cause serious burns in the lungs or on damp skin. Face shields with dust masks together with long gloves and other protective clothing must be worn.
- 5) When measuring calcium hypochlorite a plastic, glass or enameled device that is clean and dry must be used. It should only be mixed with water.

Sodium Hypochlorite

Sodium hypochlorite is much safer than calcium hypochlorite but does require much more storage space and is more costly to transport long distances.

- 1) There is no fire hazard from the storage of sodium hypochlorite but corrosion from spillage can be a problem if the facilities are not corrosion resistant and cannot be well flushed with water.
- 2) When handling the chemical, proper clothing (gloves, eye goggles, etc.) shall be worn.

2.5.2 Chlorination Procedures

Where a powdered product is used, hypochlorite solution shall be prepared in a separate tank to allow clarification by settling before it is directed to the solution storage tank serving the hypochlorinator. If the water used to dissolve the granular hypochlorite has a hardness in excess of 100 ppm, the water should be softened with hexametaphosphate (Calgon) or an ion exchange unit. Periodic purging of the metering system, with muriatic acid, may be necessary to remove calcium deposits. The acid must be flushed from the system before it is put back into use.

The stability of the hypochlorite solution is increased if the concentration is low; the pH is above 10; iron, copper and nickel content is low; and the solution is stored in the dark at low temperature.

2.6 Chlorine Residual Testing

It is important that all surface water supplies be equipped with a continuous chlorine residual analyzer and recorder as well as a continuous turbidity analyzer and recorder; this is especially so at larger plants and where water near the intake could become polluted. All surface water plants should at least be equipped with an alarm system that would indicate when the chlorination equipment malfunctions.

Ground water sources, where poor water quality and/or minimum supervision indicates a possible health hazard, should have an automatic chlorine residual analyzer and recorder equipped with a high and low residual alarm or at least an alarm system that would indicate when the chlorination equipment malfunctions.

All installations must be equipped with a permanent standard chlorine residual testing device. It is preferable to use a DPD comparator test kit, an amperometric titrator or equivalent. The amperometric titrator can be used to check the accuracy of a

continuous chlorine residual analyzer. The above methods can be used to measure a free chlorine residual in the finished water, the distribution system or in the stand pipe when an emergency or other circumstances require a free residual.

3.0 Routine Operation

3.1 Chlorine Residual

3.1.1 General

Chlorine can be present in water as either a free or a combined residual. The bactericidal effectiveness of both residual forms is markedly reduced by high pH or turbidity, while it is enhanced by a higher temperature or a longer contact time. A free chlorine residual, while a much more effective disinfectant, also readily reacts with ferrous iron, manganese, sulphides and organic material to produce compounds of no value for disinfection.

3.1.2 Requirements

For surface water treatment plants achieving low uniform turbidities (1 FTU or less) with a minimum of 2 hours of chlorine contact or for ground water supplies proven free of hazardous bacterial or viral contamination but still requiring chlorination, the minimum total chlorine residual shall be 0.2 mg/L. For all other chlorinated supplies the minimum total chlorine residual shall be 0.5 mg/L. These are minimum acceptable residuals not target or objective residuals. A minimum contact time of 15 minutes (preferably 30 minutes) before the first possible consumer shall be provided at all times. The chlorine residual should be differentiated into its free and combined portions. It is preferable that most of the residual be a free residual. Adequate disinfection may not occur at these minimum levels if the pH is above 7.5 or the turbidity above 1 FTU.

As circumstances demand the minimum requirements for chlorine residual and/or contact time may be increased.

The chlorine residual test must be performed as frequently as needed to ensure that an adequate chlorine residual is maintained at all times. Such considerations as raw water quality and the resultant variation in chlorine demand, and changing flow rates must be taken into account.

The accuracy of an automatic chlorine residual analyzer shall be checked daily. This shall be accomplished using the amperometric titrator. The results of the check shall be inscribed on the recording chart along with the date and operator's initials opposite a mark indicating the time of the check.

A chlorine residual should be maintained in all parts of the distribution system. This will do little to protect the supply in the event of a main break or some other disaster but should control nuisance growths. The residual should be differentiated into its free and combined portions. The pH of the sample should also be recorded so that the major chlorine constituents in the water can be determined.

The amount and type of chlorine residual present when routine bacteriological samples are taken should be recorded, because this allows a more complete evaluation of the condition of the distribution system.

3.1.3 Determination

A representative sample of chlorinated water should be tested. From a tap, the water should be kept running for 5 minutes before taking the sample.

The time when the chlorine residual test should be made depends on where the sample was taken. If the sample has just been chlorinated it should be held for 15 minutes to simulate the minimum contact time, in a covered, demand-free container away from light and heat. However, a sample from the distribution system or finished water after a contact chamber should be tested immediately.

Determination of a chlorine residual should be done by one of the methods outlined in the most recent Standard Methods (14th Edition, 1976) which are preferable to the regular orthotolidine test which has been used extensively. At present the most widely accepted methods are the DPD (diethyl-p-phenylene diamine), both titrimetric and colorimetric, and the amperometric titration. For small water treatment plants or field testing a DPD comparator kit is accepted.

When using the DPD colorimetric (comparator) test a few important procedures must be observed.

- 1) The glass cell must be thoroughly rinsed after each test, since any trace of the potassium iodide (Tablet #3) will cause the chloramine colour to develop in the next test for free chlorine.
- 2) To facilitate dissolving the tablets, they can be crushed while still in their tinfoil packets.
- 3) Disintegrate tablet #1 in a few drops of the sample in the test cell. Fill the test cell to 10 ml and mix rapidly.
- 4) The free chlorine residual must be read within 30 seconds of adding the sample to the cell.
- 5) The total chlorine residual is determined by adding tablet #3 (crushed) to the same sample in the test cell, mixing, waiting 2 minutes for the full colour to develop and then reading the results in the comparator.

3.2 Records

Minimum records shall include:

- 1) Daily records of the chlorine used and scale readings.
- 2) Results from all chlorine residual tests, together with the flow rate and chlorine feed rate and the time of testing.

- 3) The daily water consumption and the chlorine dosage in milligrams per litre.
- 4) Details on chlorine cylinder changes, orders and chlorine on hand.
- 5) Monthly and yearly summaries of chlorine consumption and feed rates.
- 6) For surface supplies, daily air and water temperatures and weather conditions eg. rain, cloud, sunny, snow etc. together with wind direction and strength.

4.0 Emergency Operation

At all facilities supplying municipal drinking water, a procedure to follow in case of emergency (ie. plant malfunction) must be developed. A list of procedures for the operator to follow must be posted in a prominent location in the plant.

This list must include:

- 1) The order not to pump unchlorinated or inadequately chlorinated water to the distribution system.
- 2) The name, address and telephone number of:
 - a) Senior supervisory personnel,
 - b) Medical Officer of Health and an alternate in the regional health unit if the Medical Officer of Health cannot be reached,
 - c) The local M.O.E. District Officer and an alternate,
 - d) Chlorinator service company (to be called only if chlorinator needs servicing),
 - e) Chlorine supplier (to be called when chlorine required or when tanks malfunction).

- 3) The exact procedure to follow in order to increase the total chlorine residual leaving the plant to a minimum of 1.5 mg/L.

Wherever chlorination is required, the Ministry of Environment and the Medical Officer of Health must be notified immediately if unchlorinated or inadequately chlorinated water (total residual below 0.2 or 0.5 mg/L or level required) is directed to the distribution system. If this has occurred the Ministry of Environment may require the chlorine feed rate to be increased to provide a 1.0 mg/L or higher residual leaving the plant. Extensive flushing may also be required to carry the residual through the distribution system. Depending on the circumstances additional steps may be required.

When the chlorine residual is increased all customers who may be adversely affected must be notified.

5.0 Adverse Bacteriological Results

When the results from bacteriological samples collected from the distribution system indicate unsatisfactory water quality on the basis of the Ontario Ministry of Environment Drinking Water Objectives, (presence of fecal coliform bacteria or the numbers of coliform bacteria five or more per 100 ml) the procedures to follow immediately are:

- 1) Notify the Ministry of the Environment (increased chlorine residuals may be advised),
- 2) Collect further samples to confirm the results and determine the extent of the contamination. Chlorine residuals should also be recorded.

If these samples still show unsatisfactory water quality, the Medical Officer of Health and the Ministry of the Environment must be notified and the chlorination increased to provide a total

chlorine residual of 1.0 mg/L or a free chlorine residual of 0.2 mg/L at the end of the distribution system. Systematic flushing or swabbing may be necessary in order to achieve and maintain a residual at the ends of the distribution system.

A thorough study of the treatment plant and/or distribution system should be undertaken to determine the cause of the adverse bacteriological results. If the conditions warrant it the Ministry of Environment should recommend to the Medical Officer of Health that a boil-water advisory be issued.

When the bacteriological samples indicate poor water quality (coliform bacteria present at levels below five per 100 ml in more than 10% of the monthly samples or other indicator bacteria - see MOE Drinking Water Objectives) the Ministry of the Environment may recommend some of the following procedures:

- 1) Initiate chlorination on an unchlorinated supply,
- 2) Increase the chlorine residual requirements in the finished water to 1.5 mg/L or more, and maintain the level until notified by MOE,
- 3) Establish a total or free chlorine residual to the end of the distribution system,
- 4) Disinfect the distribution system as for new mains (Sec. 6.2),
- 5) Undertake a thorough resampling of the distribution system which should continue until the water quality is again acceptable.

6.0 Disinfection of New and Repaired Mains

6.1 Preparation

Chlorine is predominantly a surface active disinfectant that will not penetrate debris rapidly to kill microorganisms. This

debris may also react with the chlorine to reduce its disinfecting power. For these reasons, prior to disinfection of new or repaired works, all the debris must be removed. This can be achieved by extensive flushing with potable water, preferably with foam swabs.

6.2 Disinfection of New Water Mains

There are three procedures outlined in the AWWA Standard C601-68.

a) Continuous Feed Method

After the main has been cleaned, potable water with a chlorine residual of at least 50 mg/L is fed into the main until it is full. This is achieved by having a constant flow rate and injecting a hypochlorite solution into the main with a hypochlorinator or using liquid chlorine through a solution-feed chlorinator and booster pump. The chlorinated water should remain in the pipe for a minimum of 24 hours, during which time all valves and hydrants are operated to ensure their disinfection. At the end of the 24 hour period, the chlorine residual must be no less than 25 mg/L or the procedure must be repeated.

b) Slug Method

This method is suitable for large, long mains where continuous feed is impractical. Following cleaning, potable water is fed into the main at a constant rate. Chlorine is added to the water at a constant rate so that the resulting residual is no less than 300 mg/L. The chlorine dosage is continuous for a sufficient period to ensure that the minimum contact time is 3 hours. As the chlorinated water flows past, all valves and hydrants etc. must be operated to ensure their disinfection.

c) Tablet Method

This method is best suited to short, small diameter mains (up to 30 cm (12 inches)). Since the preliminary cleaning must

be forgone it is absolutely essential that during construction the pipe interior remains clean and dry. The calcium hypochlorite tablets must be placed at the top of the pipe using an approved adhesive. The main is slowly filled (flow less than 0.3 m/s (1 ft/s)) to prevent washing the tablets to the end of the main. Sufficient tablets must be used to result in a final chlorine residual in excess of 50 mg/L. The contact time is a minimum of 24 hours after which the residual must be about 25 mg/L. If the water temperature is below 5° C the contact time must be increased.

6.3 Disinfecting Repaired Water Mains

When a leak is minor and the water in the main always has a positive pressure, no disinfection is required after the repair is complete. However, with a more serious break the main must be disinfected before being put back into service. AWWA Standard, C601-68 lists two alternatives. If the broken main need not be put back into service immediately the methods outlined for new mains would ensure better disinfection.

a) Swabbing and Flushing

This procedure is the minimum that may be used. The interior of all pipes and fittings must be swabbed with a 5% hypochlorite solution as they are installed. The chlorine solution can be sprayed on with a small pressurized tank. This is followed by flushing, preferably in both directions, until the coloured water is eliminated.

b) Slug Method

Where possible, the following method should be used. The main with the break is isolated and repaired, then flushed and if necessary foam swabbed to remove all debris. Chlorine is then introduced, as in Sec. 6.2 b), except that the residual may be increased to 500 mg/L and the contact time reduced to $\frac{1}{2}$ an hour.

After the contact period the main is well flushed and then put back into service.

6.4 Bacteriological Testing

After the new or repaired main has been well flushed with potable water, to remove the heavily chlorinated water, bacteriological samples must be taken to test the effectiveness of the disinfection. If the main is very long several samples should be collected along its length. In distribution systems that normally carry a free chlorine residual one sample or a set of samples (in a long main) is sufficient. However in all other distribution systems a second sample or set of samples should be collected after 24 hours. A main is considered adequately disinfected if there are no detectable coliforms in any of the samples.

New mains must not be put into service until the coliform tests are acceptable. The disinfection process must be repeated if they are not.

If possible repaired mains should also be kept out of service until acceptable results are received. This is seldom possible but if fecal contamination of the main is known or suspected it must be done to prevent a public health hazard. If the test sample(s) are positive for coliforms the disinfection should be repeated.

7.0 Disinfection of New or Repaired Reservoirs

7.1 Preparation

As with water mains, the interior of storage facilities must be cleaned and free of debris before attempting the disinfection process. This is accomplished by washing down the walls and floors with high pressure jet cleaning equipment and/or long handled brushes. All the debris must be rinsed from the tank interior before disinfection.

7.2 Disinfection Procedures

Three methods for disinfection are as follows:

a) First Method

This is suitable for tanks where gross contamination has occurred. The tank is filled with potable water to which has been added, early in the process, sufficient chlorine to result in a 50 mg/L residual when the tank is full. The tank is left for at least 6 hours, preferably 24 hours, then drained to waste and refilled from the regular supply.

b) Second Method

This method can be used in a relatively clean reservoir, such as following routine cleaning or repair. The walls, floor, and stanchions are sprayed with a 200 mg/L chlorine solution. The tank is well flushed, filled with potable water from the distribution system and put into service.

c) Third Method

This is an alternative to the second method. Sufficient chlorine is added to the tank to result in a total chlorine residual greater than 2 mg/L when the tank is later filled. Initially the tank is only partially filled until the chlorine residual is 50 mg/L. After a 24 hour contact time the tank is totally filled and allowed to stand for a further 24 hours. The tank is now put into service without draining.

7.3 Bacteriological Testing

After the new or repaired reservoir has been filled with potable water, bacteriological samples must be taken to ensure adequate disinfection. If a free chlorine residual is usually carried in the system only one set of samples is required but in all other systems a second set of samples should be collected after 24 hours.

With a new or grossly contaminated reservoir the bacteriological samples must show no detectable coliforms before the

reservoir is put into service. If coliform bacteria are detected, the disinfection process must be repeated.

With a repaired reservoir, if coliform bacteria are detected in the samples, the disinfection process should be repeated.

8.0 Discharge of Chlorinated Water

Chlorinated water, as used in the disinfection of water mains and reservoirs, can be very toxic to aquatic organisms and it should not be disposed of without careful thought to its effect on the receiving water or sewage treatment plant (STP).

Chlorinated water can be discharged to:

- 1) Sanitary Sewers - This is a safe course to follow especially if the volume is not great and there is a considerable distance from the point of addition to the STP. However if there is a large volume, eg. with a reservoir, it is essential to contact the municipality to ensure that the operation of the STP is not adversely affected by a hydraulic overload or a massive slug of water with a high chlorine residual.
- 2) Receiving Waters - This can be detrimental to aquatic life and many fish kills have resulted. Water with a free chlorine residual should not be discharged to a stream or lake. If a combined chlorine residual is present, the concentration at the edge of the mixing zone (where allowed) should be below 0.002 mg/L.
- 3) Storm Sewer - This should be thought of as directly connected with the receiving water and the same restrictions should apply, even though there could be considerable dilution during wet weather.
- 4) Drainage Ditch - Discharge to an open ditch is a good alternative, especially if the point of addition is a

considerable distance from the receiving water and the ditch is unlined and is full of weeds and other organic material. Sunlight and high temperatures would help to dissipate the chlorine quickly.

If the above conditions cannot be met, a slow discharge of the chlorinated water to a sanitary sewer or ditch can be used. This is easier and cheaper than dechlorination. If dechlorination is necessary (ie. with direct discharge to a small stream), there are several chemicals that can be used effectively. Adequate mixing and dosage of the chemical with the chlorinated water must be ensured. The amount of dechlorination chemical required can easily be determined from the following equation.

Excess chlorine residual x Factor = Dechlorination chemical required

This can be worked out in mg/L, lb's or what ever units are appropriate.

There are five chemicals that can be used to dechlorinate the water:

- 1) Hydrogen Peroxide - (Factor = 0.479) - This is probably the best chemical when discharging to an environmentally sensitive water course. It is cheap and an overdose will only add more oxygen to the stream.
- 2) Sulphur Dioxide - (Factor = 0.901) - This chemical is cheap but it will slightly lower the pH in the receiving water.
- 3) Sodium Thiosulphate - (Factor = 2.225) - This will cause some sulphur turbidity but an excess is harmless.
- 4) Sodium Sulphite - (Factor = 1.775) - Excess will lower the dissolved oxygen in the stream.
- 5) Sodium Pyrosulphite - (Sodium Metabisulphite) - (Factor = 1.338) - Excess will lower the dissolved oxygen in the stream.

chlorine dosages for the treatment of water

PURPOSE OF CHLORINATION	DOSAGE IN PPM ¹	CONTACT TIME IN MINUTES	RECOMMENDED TYPE	RESIDUAL PPM
Disinfection: With Combined Residual ²	1.0-5.0	Requirements determined by local health authorities	Free	0.1
With Free Residual ³	1.0-10.0			
Ammonia (NH ₃ -N) Removal	10xNH ₃ -N content	20 ⁺	Free	0.1
Taste & Odor Control	10xNH ₃ -N content plus 1.5 ppm	20 ⁺	Free	1.0
Hydrogen Sulfide (H ₂ S) Removal	2.22xS content to free sulfur 8.9xS content to sulfate	Instantaneous	Free or combined	0.1
Iron (Fe) Removal ⁴	0.64xFe content	Instantaneous	Combined	0.1
Manganese (Mn) Removal ⁴	1.3xMn content	Variable	Free	0.5
Red Water Prevention	Maintain a free residual in dead ends	Variable	Free	0.1
COLOR REDUCTION	1.0-10.0	15	Free or combined	0.1
Algae Control	1.0-10.0	Variable	Free	0.5 ⁺
Slime Control	1.0-10.0	Residual needed throughout system	Free	0.5 ⁺
Control of Iron and Sulfur Bacteria	1.0-10.0		Free	1.0 ⁺
Coagulation Aid for Preparation of: Activated Silica Chlorinated Copperas	1.56 lb. per gal. 41 Baumé Na ₂ SiO ₃ 1 part per 7.8 parts FeSO ₄ • 7H ₂ O	Not Applicable		

Combined residual means the residual produced by the reaction of chlorine with the natural or added ammonia, or with certain organic nitrogen compounds.

Free residual means the residual produced after the destruction with chlorine of ammonia, or of certain organic nitrogen compounds.

Filtration is also required.

PENNWALT

WALLACE & TIERNAN
DIVISION

**chlorine dosages for
the treatment of sewage**

PURPOSE OF CHLORINATION	DOSAGE IN PPM	RECOMMENDED RESIDUAL IN PPM
Disinfection of:		
Fresh Raw Sewage	6-12	
Septic Raw Sewage	12-25	
Fresh Settled Sewage	5-10	
Septic Settled Sewage	12-40	
Chemical Precipitation Effluent	3-10	
Trickling Filter Effluent	3-10	
Activated Sludge Effluent	2-8	
Sand Filter Effluent	1-5	
Odor Control:		
Up Sewer	1.5-10	0
At Plant	5-10	0
Activated Sludge Operation:		
Sludge Bulking Control	2-8	0
Sludge Thickening	Variable	1.0
Trickling Filter Operation:		
Odor Control	2-6	0
Filter Pooling	5-40	1.0-2.0
Filter Fly Control	3-10	0.1
B.O.D. Reduction	6-12	0.2-0.5
Imhoff Tank Foaming	3-15	0
Digestor Supernatant	20-80	0-trace

chlorine dosages for the treatment of swimming pool water

The chlorine dosage requirements of swimming pool waters are dependent on the type and magnitude of the chlorine residual required. This is usually governed by regulatory health authorities.

The conditions which affect the chlorine requirements include continuity of recirculation, rate of recirculation, efficiency of filtration, the number and location of the pool inlets for filtered water, the bathing load, the type and shape of the pool, the type of chlorine residual produced, pH and alkalinity.

The dosage rate can be based either on pool capacity or on the recirculation rate. Both methods of calculation are used very extensively.

The recirculation rate can be obtained by noting the pump capacity or by multiplying the capacity of the pool by 3, where the turn-over rate is three times in 24 hours; or by 4, where the turn-over rate is four times in 24 hours; or by any other turn-over rate that may be in use in any particular instance.

The usual chlorine dosages, unless otherwise directed by local health regulations, are as follows:

TYPE OF POOL	CHLORINE APPLICATION BASED ON RECIRCULATION RATE	
	Average Minimum	Average Maximum
Indoor	2.0 p p m	5.0 p p m
Outdoor	3.0 p p m	10.0 p p m



SUBJECT:

WATER TREATMENT OPERATION

TOPIC:

Care, Maintenance and
Operation of a
Distribution System

OBJECTIVES:

FOR INFORMATION ONLY:

CARE, MAINTENANCE & OPERATION OF A WATER DISTRIBUTION SYSTEM

General

Without an adequate maintenance programme, even the best installed systems will deteriorate. Problems common to neglected systems include:

1. Fire hydrants that will not produce the necessary volumes and pressures.
2. Undesirable taste or odours within the distribution system caused by
 - a) dead water - dead ending mains
 - b) rerouting of water - change of flow direction
 - c) lack of a routine flushing program.
3. Leak repair work or maintenance requiring shut off.
4. Reduced water flow caused by incrustations lining the mains.
5. Frequent water main breaks as a result of freezing lines and services.

NEW DISTRIBUTION SYSTEMS

Disinfection

Chlorination of all new works is required; however, it is effective only in disinfecting the surfaces. It does not remove foreign material (occasionally animal or foreign matter is left in the main) during construction. The Ministry requirements for disinfection are detailed in Bulletin 65-W-4.

Lines

New lines must be swabbed or pigged. Although the swab will not move a wood block, the loss of two or three swabs may indicate trouble. The practice of eliminating "pigging" or swabbing the mains to save money is a foolish risk.

All main repair work must be adequately disinfected to Ministry standards. No one will object to the generous use of chlorine when disinfecting mains.

Valves

All valves and valve boxes adjacent to or part of construction projects must be inspected regularly during the work to ensure that all conditions are satisfactory. The location of every valve in the system must be itemized on the municipal map.

Valve boxes must be adequately protected from vandalism.

All valves should be closed and opened at least once a year. Since gate valves are constructed of different metals, corrosion can take place on the moving faces unless they are routinely flushed by regular operation. Valve blockages can sometimes be flushed by partially closing the valve, closing an adjacent main valve, and opening a hydrant between the two. All valves should operate in the same direction if possible to avoid damage when an overeager helper tries to open the valve in the wrong direction. Very little can be done to maintain buried valves without excavation.

MAINTENANCE

Pipes

Proper installation can be the best aid to maintenance. Pipes should be laid by hand on the bottom of undisturbed soil in a trench. Main leaks and breaks occur most frequently in the winter when contractions due to cold trouble the system with assistance from:

1. Thin pipe walls as a result of corrosion.
2. Improper bedding allowing pipes to sag. It can cause circular breaks in small pipes and in larger pipes splits result from ring stresses.

3. Metal fatigue from vibration.
4. Water hammer.
5. Construction activity adjacent to the piping.

To Repair:

1. *Circumferential break - split sleeves.*
2. *Longitudinal break - dewater main and install a new section.*

After excavation and repair, back fill using granular material (3/8" crushed stone). At *Rubber Joints* adequate blocking or strapping should be provided at bends, change of direction points, or at end of line.

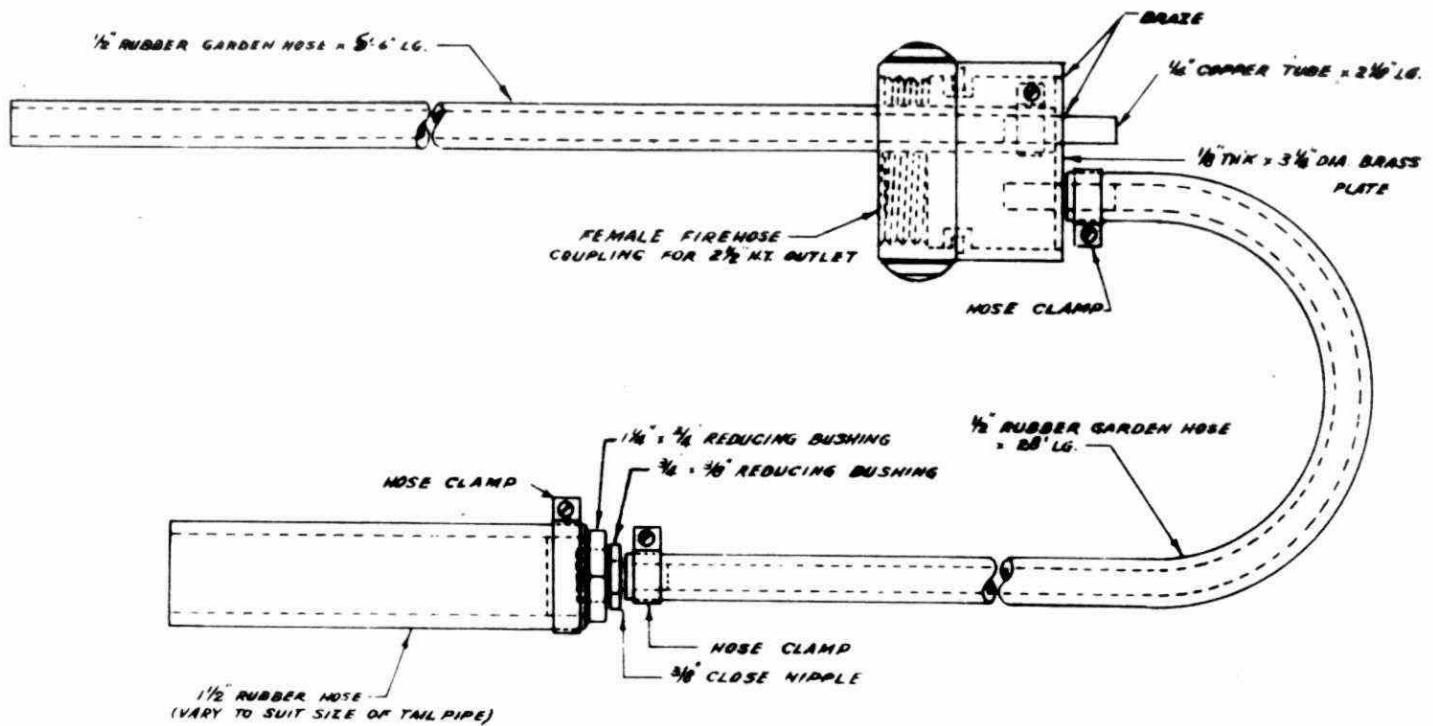
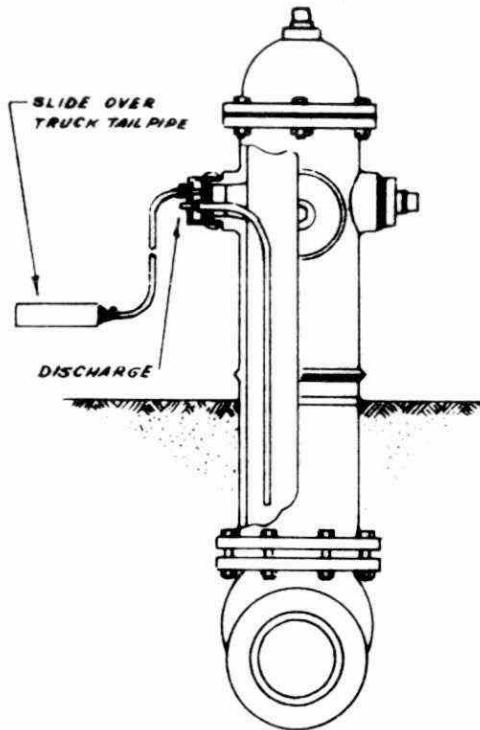
Hydrants

Hydrants are frequently the only portion of the distribution system actually seen by the public and therefore should be kept in good condition and painted. They should be properly drained to minimize chances of contamination or freezing. In areas where high water table floods the hydrant barrel, drains should be plugged and the hydrant pumped dry after every use. Routine pumping should be carried out at problem hydrants to ensure that no damage due to freezing takes place. When self-draining hydrants are in use, hose nozzle caps should not be replaced immediately. Allow the hydrant barrel to drain. (See Figure 7-1 for details of an exhaust powered ~~hydrant~~ pump.)

Antifreeze in the hydrant barrel may enter the water main with a drop in pressure, constituting a potential health hazard. Its use is not recommended.

Hydrants should be checked at least twice every year (Spring and Fall). Items to check include:

1. Stuffing box
2. Valve
3. Valve seat
4. Barrel (for cracks)



EXHAUST POWERED HYDRANT PUMP

FIGURE 7-1

5. Drain parts (if in use)
6. Threads
7. Geared opening mechanism and gaskets

Although it may be desirable to use hydrants only for fire fighting, other uses might be allowed for a nominal sum or by payment for the water used. An auxiliary valve should be installed on one of the hose nozzles to permit only authorized personnel to operate the hydrant at the start and end of the required period. This prevents damage from improper and repetitive hydrant operation. They should be opened or closed slowly to prevent water hammer in the rest of the distribution system.

Reservoirs

Elevated storage, stand pipes and ground storage require routine inspection and maintenance to ensure they are not the source of water quality problems and excessive leakage. Tanks and stand pipes should be drained and inspected each year to ensure that severe corrosion does not proceed to the point of failure. Tanks should be cleaned and painted routinely. *Safety regulations governing work in confined spaces must be met at all times.* Ground storage should be emptied and the slime and deposits removed regularly. *The works must be disinfected before being returned to service.*

PROBLEM SOLVING IN DISTRIBUTION SYSTEMS

Taste, Odour and Colour Problems

Problems may be generated:

1. Within dead areas where water becomes stagnant and deoxygenated (flat).
2. When turbidity and iron settle out in the mains.
3. When iron and sulphur bacteria are allowed to build up and cause offensive odours.
4. Through internal corrosive action on mains due to aggressive water (low pH).

A flushing and foam swabbing programme can be of some help in controlling water discolouration. If the programme fails to help, technical aid should be called in immediately.

Adverse Bacteriological Sampling

If the results obtained on routine samples indicate bacterial contamination, *inform the local health unit and MOE nearest Regional or district office immediately.* An intensive resampling program must be instituted to immediately trace the cause or origin of the problem. The operator should:

1. Resample the raw and treated water.
2. Resample the location of the bad sample.
3. Take sample from consumers on either side of bad sample.

On-the-spot chlorination may be necessary if internal contamination has taken place. The location of equipment for use in an emergency should be known to the operator.

Leak Detection

There are two main methods of finding leaks. These may be divided into leaks that one can see, and leaks one can hear.

1. If one sinks up to the ankles in mud in a normally dry section of ground, there must be a source of water somewhere. It should be checked if there is a water main or service nearby. The fact that the surface ground is dry is no proof that there is not a water leak. Water will find the easiest path to escape and sometimes this path is not the obvious one of bubbling up through the surface. This is particularly true during the winter.

When it is snowing, one section of the ground may not have any snow on it, since the water leak raises the temperature of the ground slightly and melts the snow. When the ground is frozen, the water from the leak can travel long distances to find a spot where the frost is not solid. It will then surface at that location.

2. Leaks One Can Hear

- a) When listening for a leak, try to remember the big leaks are quiet, and the little leaks sound like Niagara Falls. Slight leaks that don't get any bigger can be tolerated; however, little leaks often wash sand into the leak, wearing the leak larger and eventually causing trouble. *Don't neglect the leaks because they are small.* The really bad leaks are the ones going into sewers or sand, carrying the water away unnoticed. If there is a bad leak, look for the general area by shutting down the mains. This must be done at night. Such a leak can be suspected when pumpage suddenly increases and doesn't drop below a certain level at night or Sunday as normally expected.
- b) There are two methods of listening for leaks. One is to use an ordinary metal rod or stick with an ear cap on one end. The end of the rod or stick is placed on any water-carrying pipe and the operator listens. Some people are expert at this simple procedure because they have used it often enough to be able to identify the sound of a leak as opposed to the sound of real water usage. Modern electrical amplifying equipment accomplishes the same result, by allowing more volume. It is often equipped with a meter. The equipment is moved from area to area, usually using hydrants as listening posts, until the area is located

where the noise is loudest. It may be necessary to shut off services at curb boxes to limit the water movement within the area under question until the exact location of the leak is established.

It is important to disinfect all exposed surfaces when repairing leaks and breaks as outlined in Bulletin 65-W-4.

OCCURRENCE OF CROSS CONNECTIONS

The passage of polluted or unsafe water into a water supply system by backflow is known as a *cross connection*. The occurrence of cross connections is not unique in any specific type of plumbing fixture or on any particular premises. The hazards may exist in homes, in public buildings, or may occur on commercial and industrial premises. Some installations vulnerable to cross connections are: water closets equipped with a flushometer, laboratory sinks, steam tables, water cooled apparatus, or any equipment with a submerged supply.

Two common types of cross connections are:

1. Back Flow
2. Secondary Supply Systems

The enforcement of stringent plumbing regulations, however, can be of great help in avoiding the most common cross connections. The Plumbing Code applying to water supply systems is designed, in part, to ensure that active and potential cross connections do not occur. Much can be done to prevent cross connections by observing the following principles of plumbing; the use of air gaps, the effective installation of back flow preventers, provision for fixture overflow, and the use of indirect supplies.

Whenever possible, there must be an air gap between the supply outlet and the flood level rim of the fixture. Unless a back flow preventer is properly installed in the distributing pipe, the orifice of the faucet or spout must be located so that the air gap complies with the plumbing regulations of the Province of Ontario.

PIPE THAWING

Occurrence of Freezing Problems

Since freeze-ups occur in most municipal systems in Ontario, the services of thawing crews are required during the winter months. Apparently, as long as a favourable balance of heat is maintained in the pipeline, freezing conditions will not develop. Frozen services are more common than frozen mains. Less water and longer periods of no motion can cause this. Insulation protects pipes from freezing. Another protection is to bury the pipes below the frost line.

Methods Used in Thawing Watermains

Frozen watermains require the application of enough heat to melt the ice and snow, permitting the water to resume flowing. Many methods have been used, including:

1. Digging down to the pipe and building a fire in the trench over it.
2. Using gasoline or torches.
3. Wrapping the pipe in rags and pouring hot water on it.
4. Using steam.
5. The use of electricity.

Except for the use of electricity, these measures involve considerable time and inconvenience, and are often messy. Pipes may be split from extreme heat when steam or open fire are used.

Electrical Thawing of Watermains and Services

The passage of electrical current through a conductor, whether it is a wire or a pipeline, encounters resistance. This resistance creates heat, the intensity depending upon the characteristics of the conductor. This is the principle behind the electrical thawing of pipes. The low melting point of lead indicates the danger of melting lead surface pipes with high currents. Iron lines heat most readily, while copper heats slowly. Whenever lead goose-necks are used, low currents should be employed.

Thawing Procedure

1. Locate the frozen section of pipe.
2. Include the frozen section in an electrical circuit by connecting cables from the source of energy to the closest convenient points in the piping system (hydrants, curb service boxes, etc., or, for service connections, exposed pipes in the house and the service shut-off).
3. Ensure that good electrical connections are made. Remove rough scale at the point where the clamp is to be fastened to the pipe or arcing may cut holes in the pipe.
4. If a house service is involved, remove the water meter from the circuit to break the connection between the service pipe and the house piping.
5. Remove the ground clamp from the water pipe to prevent stray electrical currents getting into the neutral wire and wiring system of the house.
6. Proceed with thawing.

Removal of the meter alone or disconnection of the ground clamp alone is not enough to keep the current from feeding into the house wiring circuits. Use caution. Underground contact of metal pipes or some other circuit may occur.

Some Do's and Don't's on Thawing Frozen Watermains

1. Use the least current possible to do the job. The lower the voltage, the less the chance of injury to persons or property, including piping.
2. Avoid connections which might waste current and prolong thawing. Use only generator sets equipped with meters to determine the exact amount of current used. If the meter does not indicate a current flow, this may be caused by poor connections or bad joints in the pipe, or connections which have been made to different pipe systems. *Make sure that the frozen length of pipe is included in the circuit.*
3. Avoid the possibility of shorts or ground. Current may be fed back through gas services by the water heater. *No gas pipes or furnace support wires should be in contact with the pipe being thawed.* Radio ground wiring should be detached. Heat may be detected by placing a hand on the meter couplings. To play safe, the main switch should be disconnected.
4. Make certain of the pipe material in use and make allowances in the current applied.
5. Make sure the wires from the energy sources are adequate and that a good electrical contact is made. Scraping the pipe surface may be necessary. Distance between the connections should be as short as possible and limited to the frozen piece of pipe.
6. *Open the pipe before thawing.* This will let you know if water is beginning to flow. It also avoids the possibility of steam pressure developing and doing more damage than the frozen line.

SUBJECT:

TOPIC: 9

WATER TREATMENT OPERATIONS

Records

OBJECTIVES:

The trainee will be able to recall:

1. the main reasons for maintaining plant records;
2. one method and the reason for maintaining records on the distribution system, i.e. valves, hydrants, booster stations, blow-off valves, etc;
3. the statistical entries that should be recorded on the daily operating sheets;
4. the information recorded in the maintenance log book;
5. information which can be obtained by an analysis of:
 - a) daily operating sheets
 - b) maintenance Log Book.

RECORDS

PURPOSE

Obtaining and recording information is not an end in itself. Process control test results, together with such data as flow rates, power consumption, quantity of chemicals used, hours of pump operations, recorded in an understandable (and easy to use) form must be analyzed so that the present and future operating requirements can be met. Records provide the means of ensuring proper maintenance schedules are adhered to. They provide a basis for justifying plant expansions and provide the information by which design changes can be instituted. Notwithstanding the overall importance of records, only those that can be useful should be maintained. Records for records sake means a waste of time and labour to the detriment of some important task.

The main purposes for the establishment and maintenance of a system of records are -

1. To assist the operator in solving plant problems.
2. To provide evidence that the plant is meeting the water quality objectives established by the Ontario Ministry of the Environment.
3. To provide the basis for handling complaints.
4. To determine equipment, plant and unit process performance standards.
5. To plan equipment replacement schedules, design changes and plant expansions.
6. To establish a cost base.

RECORD SYSTEMS

Record systems must be set up with two objectives in mind. Firstly, it must be as simple as possible, the form and extent of records being carefully planned. Secondly, a

procedure must be established to ensure continuity of the desired records.

Records should be permanent, with entries made in ink or indelible pencil. Ordinary lead pencil notations smudge easily or can be altered. Once a record has been made, it should be filed in such a manner that it can be easily retrieved.

Plant Operational Records

The data which is recorded at an installation will be determined by the type of treatment plant, the volume of water treated and the kind of installations tied in with the treatment plant.

Records of treatment plant operation may include information on:

1. Filter runs.
2. Wash water used.
3. Pumps in operation.
4. Chemical dosage including chlorination rates.
5. Condition of raw and treated water.
6. Flows.
7. Power consumption.
8. Results of laboratory tests.
9. Amount of chemicals used.

Source Records

Records should also be maintained for the water source(s). If it is a surface source, information on the following items should be maintained:

1. Raw water temperature.
2. Raw water quality (turbidity, colour, taste & odour).
3. Raw water quantity used.
4. Level of water in river, stream or lake.

If the source is groundwater, information recorded should include:

1. Raw water temperature.
2. Raw water quality.
3. Well logs.
4. Pumping intervals.
5. Static levels.
6. Drawdown levels.
7. Rate of replenishment.
8. Quantity of water used.

Pumping Station Records

Records for pumping stations should include:

1. Amount of water pumped.
2. Number of hours run by each pump.
3. Power consumption.

Distribution System Records

Strict procedures should be followed in relaying information on the operation and maintenance of *distribution systems* to the plant operator. A large scale comprehensive map is necessary to show all mains, their sizes and types, valves, hydrants, streets, reservoirs, elevated tanks, wells, booster stations and emergency interconnections with other systems, as well as blowoffs, air release valves and normally closed gate valves, if possible.

The original map should be carefully stored and copies issued to operating personnel for their use. As the map must include the entire system, the scale may be too small to show the required detail. Therefore, to have an adequate record, it will probably be necessary to divide the map into sections on separate sheets, using an adequate scale to show the required details. Sectional maps must be

accurately scaled so that adjoining sheets will line up. Information on sectional easements, street names and widths, mains, their sizes and locations, material, year installed, hydrants, their types and classes, details relating to valves, service lines including sizes and locations, and all other information relating to the section of the system under study should be recorded. In other words, the section map is a magnified part of the major system map which enables you to read the fine print. In large distribution systems, it is often advisable to enlarge or divide section maps for works foremen assigned to particularly congested areas.

Sectional maps are among the most important of all distribution system records. Supplements for field crew use are *valve records*. These give complete listings of all gate valves with their locations, functions, and operation. Data covers each valve number, size, make, class, number of turns to open, direction of turns to open, street location, distance and direction from the street line or curb and intersection, or other information to help locate the correct valve quickly.

Accounting Records

All accounting records may not come under the jurisdiction of the plant operator, but information that includes inventory control, costs of maintenance and time or payroll data does. The payroll records are highly important to the operator. If they are not accurate, and are not submitted to central accounting on time, he will receive complaints. With the development of machine accounting, many of the major accounting records are maintained in the form of punched cards. Later, they can be used for billing procedures and collection data.

MAINTENANCE LOG BOOK

Records should be kept in a ring binder log book. Each piece of equipment has a separate page in this book, with the following information recorded:

1. Work done.
2. Time spent.
3. Costs for any piece of equipment.

The accuracy, usefulness and reliability of the maintenance system depend upon the conscientious completion of this log book. See Figure 9-1.

Information which can be obtained by analyses of records in a log book:

1. Comparison of existing equipment.
2. Major faults and problems.
3. Evaluation of the maintenance system.

4. *Evaluation of maintenance and reliability of equipment as a basis for selection of future equipment.*
5. *Evaluation and comparison of maintenance costs for equipment.*
6. *Measures of performance and effectiveness of equipment and maintenance.*
7. *Information for discussions with suppliers and the provision of "feedback".*

Any preventive maintenance system is only a part of the overall maintenance function; its application must be reviewed with this in mind. An evaluation of the success or deficiencies of the preventive maintenance scheme can be obtained only if total maintenance data is recorded. The costs of preventive maintenance and breakdown maintenance must somehow be minimized. To achieve this, complete maintenance data must be available.

There is no magical mathematical formula to establish how much maintenance should be done. Whenever treatment is incomplete, the question to be asked is "Was enough maintenance done to prevent equipment failure?"

Not only does poor service annoy the consumer, but all water and sewage operators and maintenance personnel have a moral responsibility to ensure that the total environment, water quality, and service is not impaired.

Good maintenance in water and sewage works is in the hands of the operators and maintenance personnel.

Equipment Name :

Equipment Number:

Figure -1 Typical Log-Book Page

DAILY LOG BOOK

Another useful record is the *diary* or *daily log book*. Many miscellaneous incidents in plant operation do not fit into the regular records employed, but they should be kept in some type of permanent form and might include:

- Occasional numerical data and measurements.
- Maintenance items, replacement and repairs.
- Start-ups.
- Trouble, and various methods tried for correction in start-ups or treatment.
- Complaints from customers.
- Visits by officials and their comments.
- Reports from other agencies (such as the Ministry of Health) on inspections and tests.

and similar facts that an operator always appreciates having on hand. This information may be quickly referred to if the daily summary sheet of operation contains a cross reference. Knowledge of the date of an occurrence, even without further detail, is often helpful.

The records you keep will depend on the type of plant you operate, the amount and category of information you need to answer enquiries, and any information that will help you to operate the plant efficiently and economically. *The important items to remember in record keeping are accuracy and continuity.*

WATER SUPPLY PLANT PERFORMANCE

MUNICIPALITY _____

YEAR _____

MONTH	PUMPAGES				CHEMICAL QUALITY										PHYSICAL TESTS		PLANT TESTS	
	TOTAL FLOW MIG	AVERAGE DAY MIGD	MAXIMUM DAY MIGD	MAXIMUM RATE MIGD	HARDNESS CaCO ₃ R T	ALKALINITY CaCO ₃ R T	IRON Fe R T	CHLORIDE Cl R T	pH pH UNITS R T	FLUORIDE F R T	NITRATE N R T	TURBIDITY FORMAZIN R T	COLOUR HAZEN R T	CHLORINE RESIDUAL	FLUORINE DOSAGE			
JAN																		
FEB																		
MAR																		
APR																		
MAY																		
JUNE																		
JULY																		
AUG																		
SEPT																		
OCT																		
NOV																		
DEC																		
TOTAL																		
AVG																		
No. OF SAMPLE																		

NOTES: R-T REFERS TO RAW-TREATED SAMPLES

ALL RESULTS IN mg/l UNLESS OTHERWISE STATED.

SUBJECT:

WATER TREATMENT OPERATIONS

TOPIC: 10

WATER TREATMENT CHEMICALS

OBJECTIVES:

The trainee will be able to :

1. Name the four (4) classifications under which water treatment chemicals fall.
2. Describe the general storage and handling practices required for chemicals used in a water treatment.
3. Identify the types (categories) of chemical feed equipment used in water treatment plants.
4. Name one or more chemicals used for
 - a) Alkalinity and pH adjustment
 - b) Dechlorination
 - c) Taste and odour control
 - d) Algae control.

WATER TREATMENT CHEMICALS

TYPES OF CHEMICALS

Many of the compounds used in modern water treatment plants have appeared in the last 20 to 25 years. Major advances would include the polyelectrolyte coagulant aids, the fluoride agents and chlorine dioxide. Others show a use-renaissance such as granular carbon, potassium permanganate and caustic soda. Still others enjoy, so to speak, a change in use direction, such as sodium silicate, chlorine and granular carbon. Others continue to be the mainstay compounds: alum, chlorine, soda ash, hydrated lime, and powdered activated carbon.

Noteworthy in the improvements affecting the delivery, feeding and storage of these chemical agents are the introduction of aluminum sulphate in liquid form, carbon slurry storage, lime slurries from bulk deliveries of hydrated lime and storage of saturated soda ash slurry in water treatment plants.

The chemicals for water treatment fall into one of the following four types:-

1. "Dry type" include the nonhygroscopic and slightly hygroscopic solids.
2. "Moist" or "Hygroscopic type" includes solids which absorb moisture rapidly.
3. "Liquids" include those materials which are liquid at normal temperature and pressure.
4. "Gases" include gases at normal atmospheric pressure although they become liquid under higher pressures.

Each of the four groups requires different shipping containers or units and different handling. Chemicals used in water treatment are listed in Appendix 1. The characteristics in descriptive sequence are: name of chemical, common names in parentheses, physical characteristics, chemical formula, density, solubility, hazard, basis for purchase.

HANDLING

Greater knowledge of materials together with the availability of new corrosion-resistant materials has facilitated the tasks of both the treatment plant designer and operator. Recommendations for the use of these materials for handling specific chemicals can be obtained, on request, from the manufacturer.

Chemicals for water treatment are shipped in a variety of containers. The choice of most convenient and economical packaging may depend to a large degree upon the extent of use and proximity of the plant to the supplier. There are various types of packaging in general use since manufacturers confine their packaging to chosen types. It is interesting to note the trend towards bulk truck delivery. Basic reasons for this trend include the variety of trucks available, reduced loading costs, improved delivery service, quick unloading, customer preference and resultant saving in chemical and attendant labour costs.

The variety of modern packaging and the different forms of transportation available make appreciable saving possible through selection of the various types. The small plant may not find it possible to accept bulk deliveries, while the moderately sized plant may find bulk delivery economical for some chemicals but not for others and the large plant will find economy in bulk delivery for nearly all chemicals. Size of plant does not preclude the possibility of appreciable saving, particularly where flexibility of chemical handling procedures has been provided in the design of the plant. Use of liquid chemicals in place of dry may prove to be more economical when all the above factors are considered. The cost of liquid chemicals delivered to the water plant may be no less, but there may be appreciable saving in operational costs. Use of unit hoppers for dry chemicals in place of bags eliminates packaging costs and products waste in handling and shipping, and reduces floor space for storage as well as the time and labour in handling.

STORAGE

All handling, storage or feeding areas should be maintained in a clean, dry, well-ventilated condition. Chlorine and other gases (Sulphur dioxide, ammonia) and gaseous products should be housed separately, with exterior vents provided with fans of sufficient capacity to force positive ventilation within a few minutes.

Since chlorine is heavier than air, exhaust fans should draw from near the floor. Ammonia gas is lighter than air, therefore, the exhaust should be from near the ceiling.

Areas for dry chemical storage need ample positive ventilation to maintain dust free air to protect the health of workers and avoid hazards of fire.

Normally dry bulk chemical is stored in bins or silos constructed of steel or concrete, of which there are innumerable designs. When the bins are constructed of steel, excellent control of inventory is provided by installed level indicators.

Another storage method for those chemicals which do not readily dissolve is "slurry storage". This method is particularly popular for activated carbon, and it is utilized somewhat for the calcium lines. Storage tanks for slurry may be lined and this is essential for carbon.

The common designs of storage bins are square, rectangular or round with an inverted truncated pyramid or cone forming the bottom and passing the chemical to the hopper of some type of feeder. The vertical sides of the main body of the bin generally extend upward to provide the required capacity.

Silos are large, cylindrical, freestanding storage units. They are utilized by plants which do not have sufficiently large storage internally, in order to receive bulk chemicals in truck-load quantity, or where the source or the transportation facilities make it necessary to carry a high inventory. They are completely weather-proof and

are provided with conveying and elevating equipment for transfer of the chemicals to the in-plant supply bins. This equipment is generally of the pneumatic type.

SELECTION OF CHEMICALS

Table 9-1 shows the phases of treatment in which chemicals listed in Appendix 1 are used. In selecting a particular chemical for a certain phase of treatment the operator must consider the Jar Test results and the facilities available at the plant. Some factors are:

1. In order to obtain good coagulation and efficient use of coagulants, it is important that the treatment be carried out at the correct or optimum pH. In the case of alum, this will be within the range of pH 5.8 - 7.5, though normally within 5.9 - 6.3 sometimes less.
2. The most desirable pH at which coagulation with alum should be carried out, using the "Jar Test" techniques, followed by laboratory filtration, is usually around 6.0. Aluminium hydroxide is soluble in both acids and alkalies, and if the pH is not correct there will be excess aluminium in solution in the final treated water.
3. If the water being treated has a high pH and high alkalinity, the required alum dose will not destroy sufficient alkalinity to appreciably reduce the pH. Acid may have to be dosed in addition, to bring the pH to within the optimum range.
4. On the other hand, if the water has a low alkalinity and low pH, alkali in the form of sodium bicarbonate, sodium carbonate or lime must be added to prevent the pH from being depressed too far by the effect of the required alum dose. In either case, it is important that the sequence of addition is correct, and that the first chemical added, is mixed and uniformly distributed to the raw water before the

second is added. In the case of coagulation at low pH, it is normal to add the acid or alkali before the coagulant, although under certain conditions it may be reversed. These latter cases are unusual and are determined during jar-testing.

5. Waters of low alkalinity and also low free carbon dioxide, are unbuffered, and the addition of lime (Calcium Hydroxide) would produce a rapid increase in pH. Under these conditions it may not be possible in practice to accurately control the dose of lime to maintain the pH within the desired range. A weaker alkali such as sodium carbonate or even sodium bicarbonate, may have to be employed, although coagulation would be improved by using the calcium alkali.
6. Ferric salts and chlorinated ferrous sulphate will form floc at high pH (i.e. above 8.3) and at low pH (between 4.0 - 6.0). The high pH treatment is often employed when the water has a low colour, or where colour removal and organic matter removal is unimportant, since at this pH level, organic matter removal is poor unless high coagulant dosages are used.
7. High pH coagulation at above 8.3 requires neutralization of the dissolved carbon dioxide and this must be carried out by the addition of lime. Caustic soda or sodium carbonate cannot be used. The optimum pH may vary from 8.3-9.3 and depends mainly on the initial alkalinity of the water. If alkalinity is high, the optimum pH will be low, and if the alkalinity is low the optimum pH will be high. In this treatment, it is absolutely essential that the coagulant be added and thoroughly mixed and dispersed in the water at the correct concentration before the addition of the lime.
8. Iron salts can also be used for organic matter removal at the low pH range, but the pH of coagulation is critical in order to ensure low residual iron in the

treated water. Although there are some municipal waterworks installations (not in Canada) employing low pH coagulation with chlorinated ferrous sulphate on coloured water, a number of industrial installations using ferric sulphate or ferric chloride for organic matter removal, in this country there is very little practical published information on low pH coagulation with iron salts. Laboratory research indicates that all the iron salts do not produce similar results under otherwise identical conditions, and considerably more research into this form of treatment is planned.

9. Coagulant aids such as activated silica or polyelectrolytes are used for the purpose of increasing the efficiency of coagulation and producing tougher and more rapidly settling floc particles. The most well known of these is activated silica. Activated silica is produced by the addition of sulphuric acid, aluminium sulphate; ammonium sulphate, sodium bicarbonate, or chlorine to a solution of sodium silicate so that a silica "sol" is produced. Considerable care should be taken in adding exactly the right amount of activating agent to the sodium silicate.
10. Polyelectrolytes, coming under the general heading of "polymers" (cationic, anionic or nonionic) must always be dosed as extremely weak solutions and sometimes applied at several separate points to avoid areas of local high concentration. At present, it is not possible to predict which of the many polyelectrolytes will be effective under any set of conditions. The selection of the right material is still a matter of experiment on the plant. In general activated silica or polymers are not used unless satisfactory results cannot be obtained without them.

TABLE 10-1

PHASES OF TREATMENT IN WHICH THESE VARIOUS CHEMICALS ARE USED

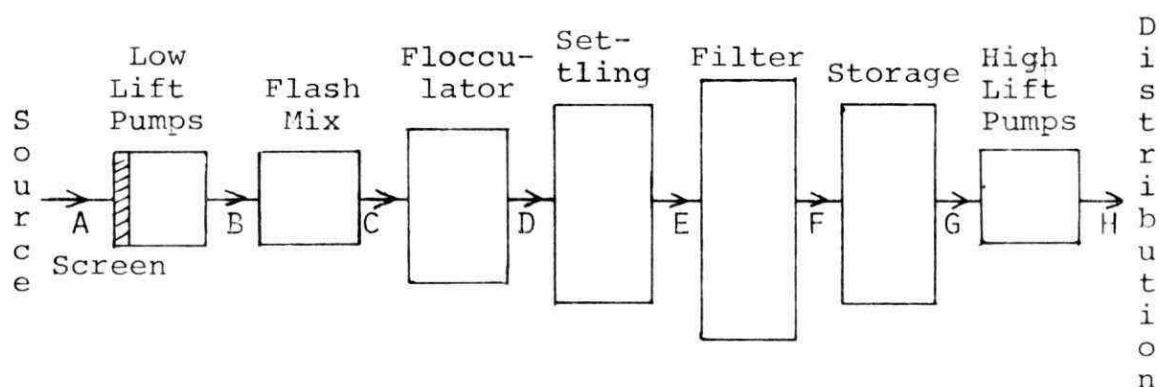
CHEMICALS	Coagulant or aid	Alkalinity & pH Adjustment	Disinfection	Dechlorination	Mineral Oxidation	Taste and Odour Control	Algae Control	Corrosion Control	Softening	Fluoridation
Activated Carbon				x		x				
Aluminum Sulphate	x									
Ammonia Anhydrous			x x							
Ammonium Hydroxide			x x							
Ammonium Sulphate	x	x								
Bentonite	x									
Calcium Hydroxide	x						x x			
Carbon Dioxide	x							x		
Chlorine			x		x x x					
Chlorine Dioxide			x		x x x					
Copper Sulphate							x			
Ferric Chloride	x									
Ferric Sulphate	x									
Ferrous Sulphate	x									
Fluosilicic Acid									x	
Hypochlorite, Calcium		x		x						
Hypochlorite, Sodium		x		x						
Ozone		x		x x						
Pot. Permanganate					x x					
Sodium Aluminate	x									
Sodium Bicarbonate		x								
Sodium Chlorite			x		x					
Sodium Fluoride									x	
Sodium Hydroxide	x							x x		
Sodium Silicate	x						x			
Sod. Silicofluoride									x	
Sodium Sulphite			x							
Sodium Carbonate	x							x x		
Sulphuric Acid	x								x	
Sulphur Dioxide				x						

The application points for chemicals related to a flow diagram are shown in Table 10-2.

TABLE 10-2 APPLICATION POINTS FOR CHEMICALS

CATEGORY OF CHEMICALS	POSSIBLE POINTS OF APPLICATION							
	A	B	C	D	E	F	G	H
Algicide	X				X			
Disinfectant		X	X		X	X	X	X
Taste and Odour	X	X	X		X	X		
Coagulants		X	X					
Coagulation Aids		X	X		X		X	
Alkali			X					
For flocculation				X				
For Corrosion control					X		X	
For softening				X			X	
Acidifier				X			X	
Fluorides							X	
Chloramine							X	
Dechlorinating								X

FLOW DIAGRAM OF WATER TREATMENT PLANT



With Solids - Contact Clarifiers,
point C is same as point D.

EQUIPMENT

The different types of equipment being used for the feeding of chemicals in the form of gases, liquids or slurries, dry granular or powdered chemicals and unstable compounds, are numerous in design, and it is not possible to cover entirely this subject matter in the limited time allotted for this topic. However, to illustrate some of the equipment which is in use in Canada, the following is included:

1. Chlorinator

Equipment of this type when used for chlorine, sulphur dioxide and ammonia, is called: a chlorinator, sulphonator and ammoniator. These dispensers can be used also for carbon dioxide and feature complete vacuum operation. The vacuum required for operation is produced by a water-powered ejector. The ejector discharge is a water solution of the gas being fed, permitting proper diffusion into the main body of water. Water to operate the ejector is obtained from the process or fresh water may be used. See Figure 10-1.

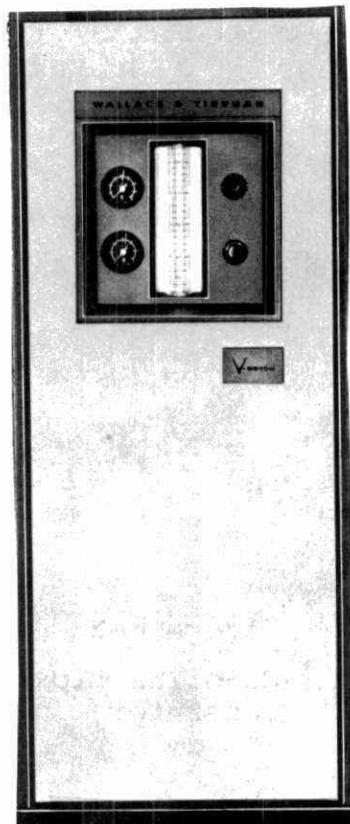


Figure 10-1

V - Notch Chlorinator

2. Chlorine Dioxide Generator

This is a device for the continuous production of chlorine dioxide which is manufactured in the plant due to instability. By merging solutions of chlorine and sodium chlorite, chlorine dioxide is produced as the chemicals mix and flow through the generator.

The generator is a flanged glass chamber filled with porcelain Raschig rings. Separate inlet connections are provided for chlorine and sodium chlorite solutions at the base of the generator and an outlet connection for chlorine dioxide at the top. The generator is secured to a panel for easy well mounting. See Figure 10-2.

In operation, chlorine from a chlorinator is fed to one of the two inlets and a solution of sodium chlorite is fed by a diaphragm pump to the other. The Raschig rings provide contact surface for the two chemicals as they mix and flow upwards. The glass generating chamber permits observation of the yellow colour produced by the presence of chlorine dioxide. See Figure 10-2a.

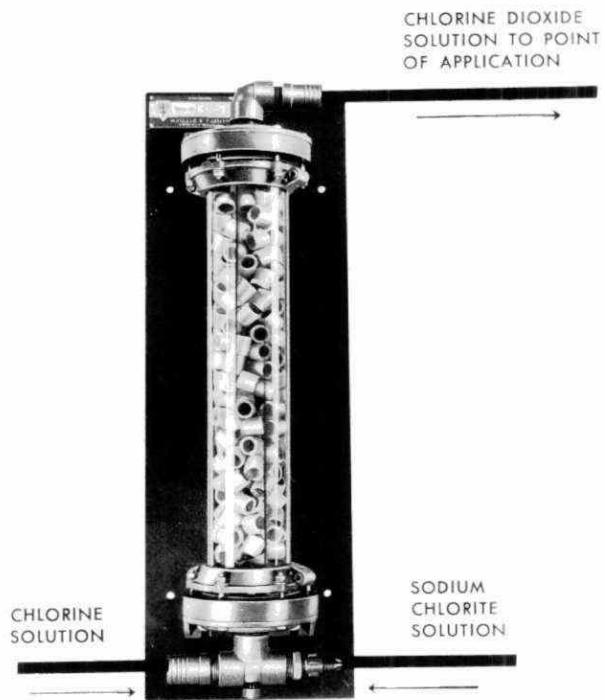


Figure 10-2
Chlorine Dioxide
Generator

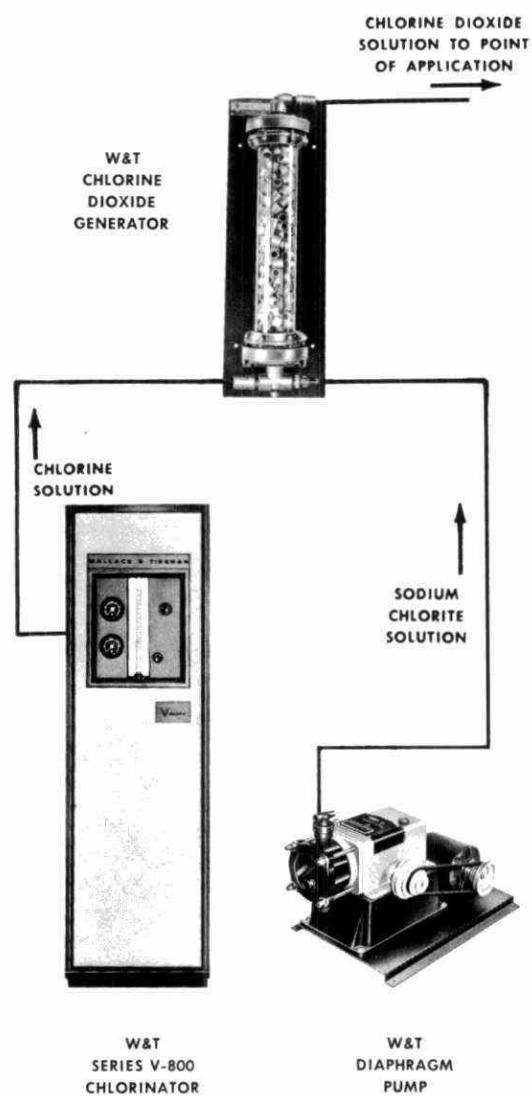


Figure 10-2a Chlorine Dioxide Generation System

3. Diaphragm or Metering Pump

This type of variable speed pump is suitable for the feeding of liquid chemicals or slurries. Both single and dual head models are available and include a 4 - step pulley for speed changes. A control knob adjusts stroke length and each head has its own indicating scale and control knob and by changing the belt on the 4 - step pulleys the discharge capacity of the pump is readily controlled. A flushing device is available also with the pump if required which is essential when feeding a slurry or a suspension. See Figures 10-3 & 10-5.

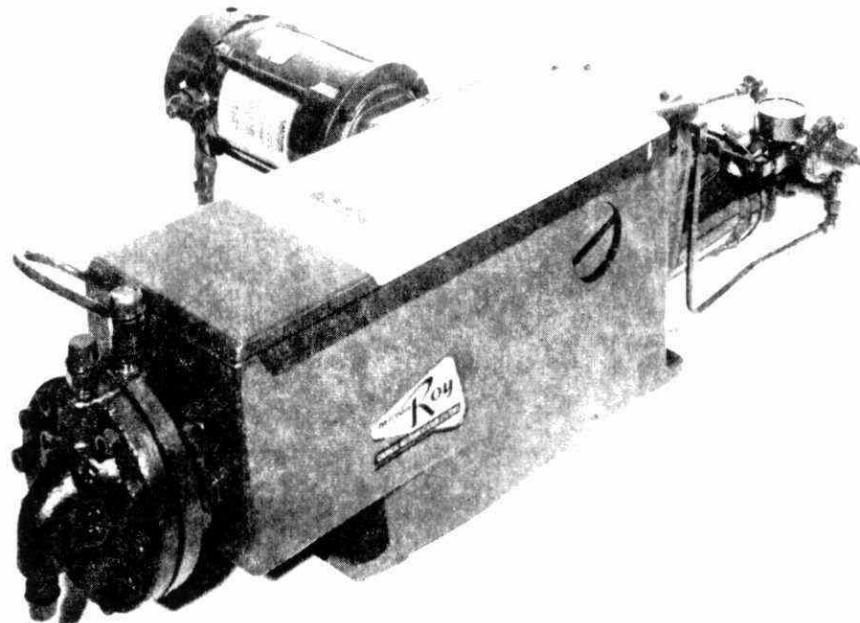


Figure 10-3 Diaphragm Pump Feeder

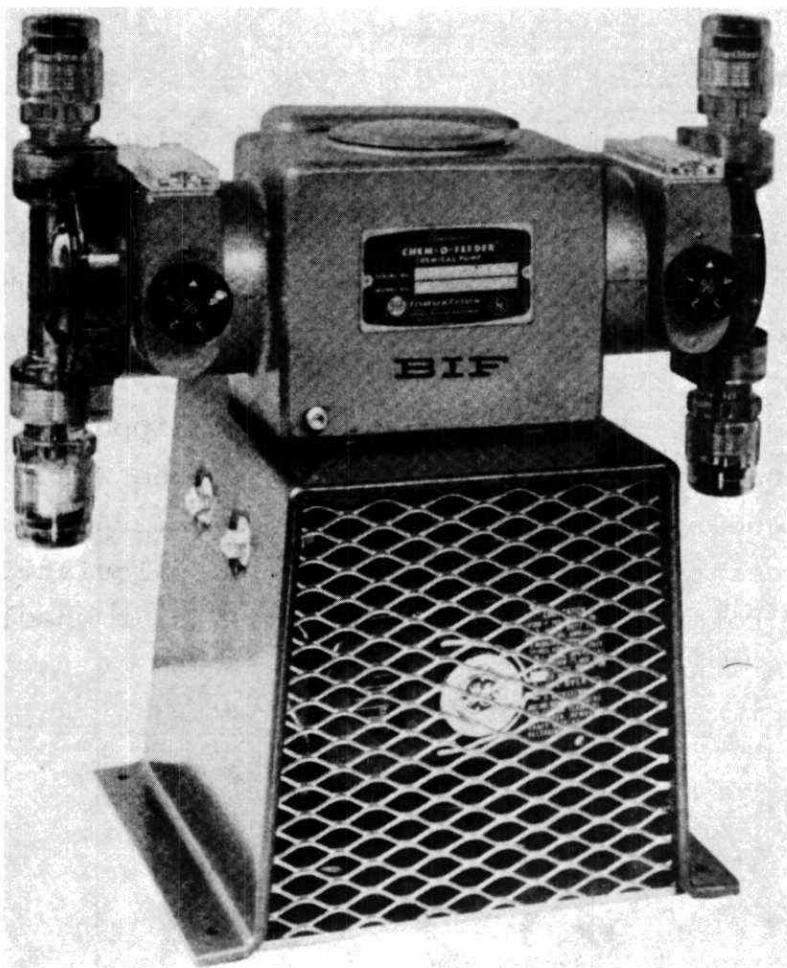


Figure 10-4
Chemical Solution
Feeder
Proportioneers

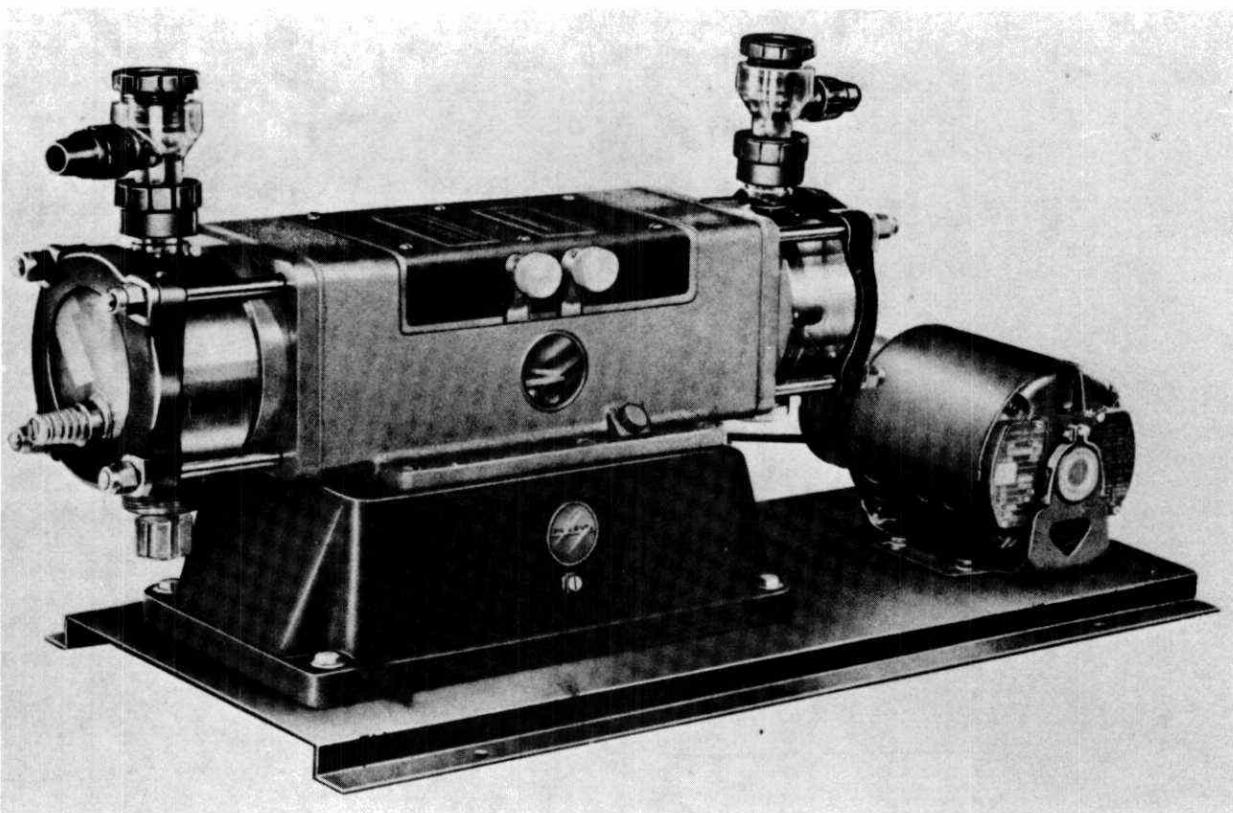


Figure 10-5
Chemical Solution
Feeder

4. Rotodip Liquid Feeder

This type of feeder consists of a tank in which the chemical solution or slurry level is maintained by an over flow weir and a float valve, a dipper wheel with several dippers transfer predetermined quantities of liquid over a baffle to the discharge section and a variable speed drive to rotate the dipper wheel. Controls for adjusting the speed of the drive to rotate the dipper wheel may be manual or automatic. Delivery of the wheel may also be changed by changing the liquid level. A totalizer is necessary since the amount fed is calculated by the number of rotations multiplied by the dipper wheel delivery per rotation. See Figure 10-6.

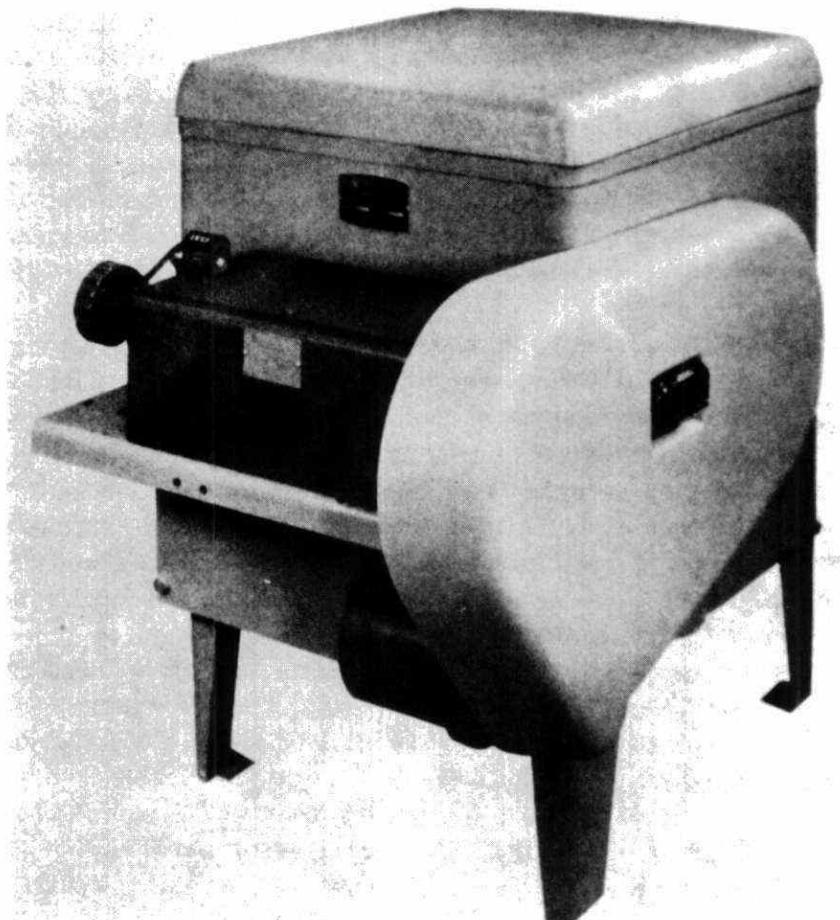


Figure 10-6 Rotodip Liquid Feeder

5. Chemical Dry Feeder

Equipment of this type is used for feeding free flowing dry granular or powdered chemicals. All dry feeding requires use of solution or slurry tanks, and this is included as an integral part of this unit with the feed mechanism mounted on the top and dropping the chemical directly into it. See Figure 10-7.

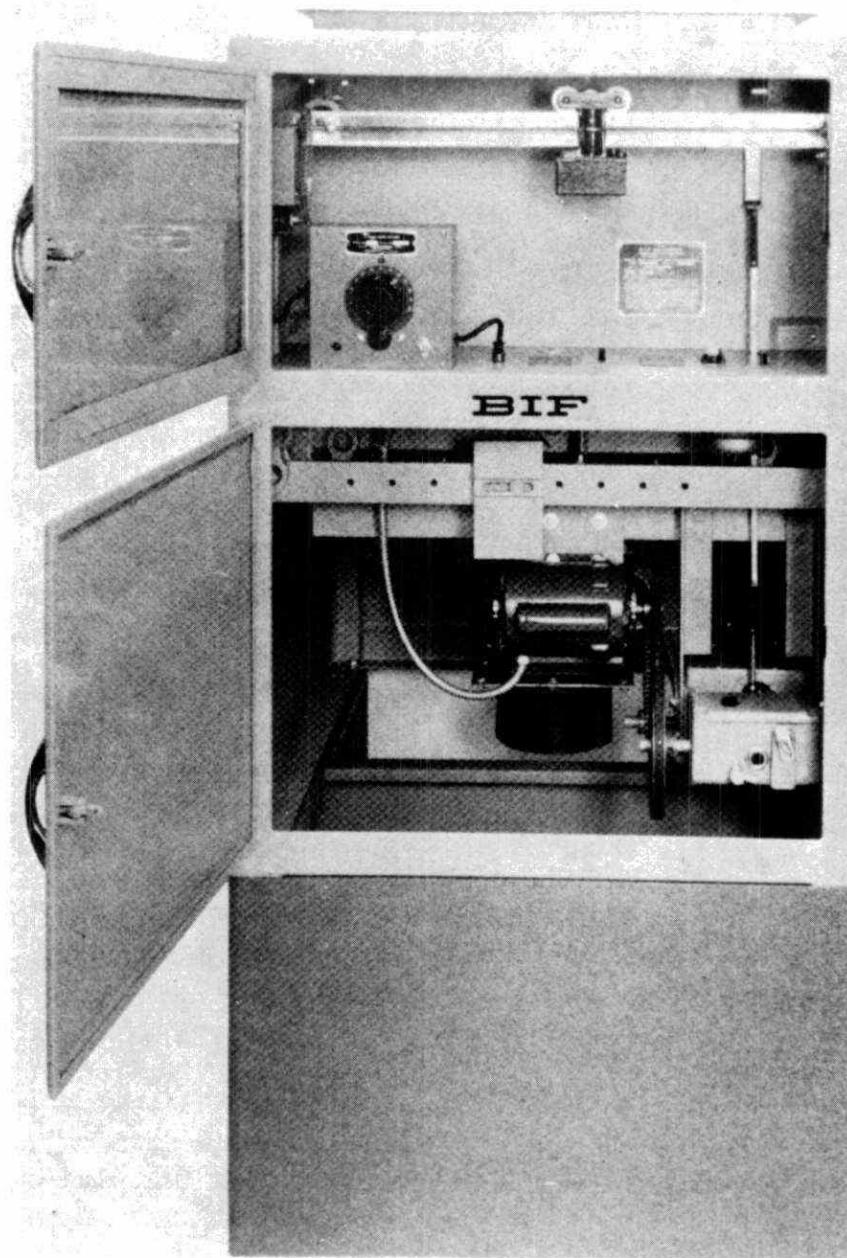


Figure 10 -7 Dry Chemical Feeder

CHEMICALS USED IN WATER TREATMENT

1. Activated carbon, (Carbon) Dry, black, powdered or granular, highly porous and adsorptive; C; 15 to 20 lbs. per cubic foot; insoluble; dust and flammable; 95 per cent C, phenol absorption value of 20 to 27.
2. Aluminum Sulphate. (Alum) 1. Dry, crystalline, white to grey, lump to powder, slightly hygroscopic; $\text{Al}_2(\text{SO}_4)_3 - \text{X}(\text{H}_2\text{O})$; 60 to 75 lbs. per cubic foot; 9.4 lb per gallon at $32^{\circ}\text{F}.$, 10.0 at $60^{\circ}\text{F}.$; irritating and astringent dust; 17 per cent soluble Al_2O_3 or 9 per cent soluble Al: 2. (Liquid), slightly brownish; $\text{Al}_2(\text{SO}_4)_3 \times \text{H}_2\text{O}$; 8.3 per cent Al_2O_3 weighs 13.4 lb. per gallon; crystallizes at $20^{\circ}\text{F}.$ with content of 8.46 per cent Al_2O_3 ; skin irritants; 8.3 per cent Al_2O_3 or 4.25 per cent Al equals 6.5 lbs dry alum per gallon. (N.B. 'X' in alum formula can vary between 7 and 18. It denotes water of crystallization.)
3. Ammonia, Anhydrous. (Ammonia) Gas, colourless, compresses to liquid, pungent odour; NH_3 ; 38.5 lb per cubic foot of liquid at 60°F ; 3.7 lb. per gallon soluble at $60^{\circ}\text{F}.$; respiratory irritant, explosive in air at concentrations of 16 to 25 per cent; 99 per cent NH_3 .
4. Ammonium Hydroxide (Aqua Ammonia) Liquid, colourless, must be contained at below $80^{\circ}\text{F}.$; NH_4OH ; 9 lb. per gallon weight at 29.4 per cent NH_3 ; solubility 29.4 percent NH_3 irritating fumes; 29.4 to 10 per cent NH_3 .
5. Ammonium Sulphate. (Sulphate of Ammonia) Dry, grey to brown crystals to fine granules, hygroscopic and cakes; $(\text{NH}_4)_2\text{SO}_4$; 60 lb. per cubic foot; 7 to 8 lbs. per gallon soluble; some irritating fumes and dries skin; min. 99.5 per cent $(\text{NH}_4)_2\text{SO}_4$ or 25 per cent NH_3 .

6. Bentonite. Dry, pellets to powder, forming a colloidal solution in water; $(\text{Al}_2\text{O}_3 \cdot \text{Fe}_2\text{O}_3 \cdot \text{MgO}) \cdot 4\text{SiO}_2 \cdot \text{NH}_2\text{O}$; ('N' refers to the number of molecules of water of crystallization) 60 lb. per cubic foot; insoluble; dust; a colloidal clay.
7. Calcium Hydroxide. (Hydrated lime, slaked lime, calcium hydrate) Dry, 200 to 400 mesh white powder, high angle of repose but when aerated flows like liquid, alkaline, very slightly hygroscopic; $\text{Ca}(\text{OH})_2$; 35 to 50 lb. per cubic foot; solubility less than 0.2 lb. per gallon; dusty and burns skin; "high calcium", 86 to 96 per cent $\text{Ca}(\text{OH})_2$, "dolomitic" less Ca but up to 30 per cent $\text{Mg}(\text{OH})_2$.
8. Carbon Dioxide. (Carbonic acid gas) Gas, compresses to liquid, colourless, odourless, non-combustible and non-corrosive (also white, solid "dry ice"); CO_2 ; liquid 68.8 lb. and solid 97.5 lb. per cubic foot; solubility 0.36 lb. per gallon at 32°F . and 0.18 lb. per gallon at 68°F .; respiratory hazard; 100 per cent CO_2 .
9. Chlorine. (Liquid Chlorine, Chlorine Gas) Gas, greenish-yellow, very pungent, non-corrosive when dry but very corrosive when wet, 463.4 volumes of gas compresses to 1 volume of greenish-yellow liquid; Cl_2 ; gas at 32°F and 1 atmosphere = 0.198 lb. per cubic foot, liquid at 32°F = 91.7 and at 68°F = 88.0 lb. per cubic foot, at 50°F . solubility = 0.096 lb. per gallon; strong respiratory irritant, also poisonous; 99.8 per cent Cl_2 .
10. Chlorine Dioxide. Gas, green-yellow, or when cooled becomes red liquid; ClO_2 ; 2.4 times the weight of air; solubility exceeds 0.1 per cent by weight; strong respiratory irritant, also poisonous; manufactured in plant due to instability.

11. Copper Sulphate. (Blue Vitriol, bluestone) Dry, blue crystals to snow, nonhygroscopic; $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$; 75 to 93 lb. per cubic foot; solubility at 32° F = 1.92 and at 86° F. = 3.12 lb. per gallon; dust and also toxic; 99 per cent $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ or 25.2 per cent Cu.
12. Ferric Chloride. 1. Anhydrous is reddish-brown crystal, deliquescent and very corrosive; FeCl_3 ; 85 to 90 lb. per cubic foot; solubility unlimited; hazardous internally and will destroy shoes and clothing; 98 per cent FeCl_3 (34 per cent Fe^{+++}): 2. Crystals are deliquescent; $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$; 60 to 64 lb. per cubic foot; 59 to 61 per cent FeCl_3 (20 to 21 per cent Fe^{+++}): 3. Liquid, at 60°F., 34 per cent FeCl_3 (11.6 per cent Fe^{+++}) weighs 12.9 lb. per gallon and 46 per cent FeCl_3 (15.7 per cent Fe^{+++}) weighs 14.4 lb. per gallon.
13. Ferric Sulphate. Dry, granular, reddish grey, free flowing, mildly hygroscopic, quite corrosive; $\text{Fe}_2(\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$; 70 to 75 lb. per cubic foot; solubility 1 part in 1 part (50 per cent); dust, hazardous internally, will ruin shoes, 18 to 22 per cent ferric iron (Fe^{+++}).
14. Ferrous Sulphate. (Coppers, iron sulphate, sugar sulphate, green vitriol) Dry, green crystals which cake, very hygroscopic; $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$; 65 to 70 lb. per cubic foot; solubility 2.4 lb. per gallon at 70°F; no special hazard; 55 per cent FeSO_4 (20 per cent Fe^{+++}).
15. Fluosilicic Acid. (Liquid Fluoride) Liquid, colourless to straw, quite stable, no appreciable viscosity; H_2SiF_6 ; 24 per cent = 12.159, 28 per cent = 12.56, 32 per cent = 12.975, 36 per cent = 13.379 per gallon; soluble in all proportions; vapours corrosive and respiratory hazard, slow irritant to skin; 24 to 36 per cent H_2SiF_6 = 19 to 28.6 per cent F.

16. Hypochlorite, Calcium. (HTH, Perchloron, Pittchlor)
Dry, granular to powder or tablets, white to yellowish, hygroscopic; $\text{Ca}(\text{ClO})_2 \cdot 4\text{H}_2\text{O}$; 52.5 lb. per cubic foot; soluble to 3 per cent available chlorine; fumes poisonous and irritating to the skin; 70 per cent available Cl_2 .
17. Hypochlorite, Sodium. (Chlorine bleach, bleach liquor)
Liquid, light yellow, strongly alkaline, very active, NaOCl ; 11.76 to 12.0 lb. per gallon; soluble in all proportions; slight fumes are irritating; flammable with materials such as oil, grease, paper, glycerine; 12 to 18 per cent available Cl_2 .
18. Ozone. Gas, colourless, sweetish odour, very strong oxidant; O_3 ; 1.658 times the weight of air, soluble to 0.5 per cent by weight; inhalation must be limited; manufactured at the water plant due to instability.
19. Potassium Permanganate. Dry, purple, solid granules, hygroscopic, powerful oxidant; KMnO_4 ; 90 lb. per cubic foot; solubility at 32°F . = 0.3 and at 68°F = 0.6 lb. per gallon; poisonous, dust, also fumes from solution; 97 to 99 per cent KMnO_4 .
20. Sodium Aluminate. (Soda Alum) 1. Dry, white to greyish, crystals, odourless, slightly hygroscopic; NaAlO_2 ; 45 to 60 lb. per cubic foot; soluble to 3.6 lb. per gallon at 68°F ., (contains 6 to 8 per cent insolubles); strong alkali causes skin burns; 46 to 55 per cent Al_2O_3 + 31 to 35 per cent Na_2O + 5 per cent NaOH : 2. Liquid, nearly colourless; at 27° Be = 32 per cent $\text{Al}_2\text{O}_3 \cdot \text{Na}_2\text{O}$ + 9 per cent NaOH .
21. Sodium Bicarbonate. (Sodium Hydrogen Carbonate or Baking Soda) Dry; white powder; free flowing; odourless; slightly hygroscopic; NaHCO_3 - 130 - 138 lb. per cubic foot. Solubility at 32°F = 0.69 lb per gallon and at 140°F = 1.64 lb. per gallon; dusty no special hazard; 99 to 100 per cent NaHCO_3 .

22. Sodium Carbonate. (Soda Ash) Dry, White powder, free flowing, slightly hygroscopic; Na_2CO_3 ; extra light, light and dense grades = 23, 35 and 65 lb. per cubic foot; at 32, 50 and 68°F . solubility is 0.7, 1.0 and 1.8 lb. per gallon; dust hazard, and solution is caustic; 99 per cent Na_2CO_3 or 58 per cent Na_2O .

23. Sodium Chlorite. 1. Dry, White to **orange**, flake or powder, slightly hygroscopic, powerful oxidant; NaClO_2 ; 50 lb. per cubic foot; at 41° , 63° and 68°F . solubility is 3.36, 3.84, and 4.56 lb. per gallon; fire hazard when dry on clothing or with organic matter or sulphur, may react violently with spark, heat, pressure or scraping; 78 to 85 per cent NaClO_2 : 2. Liquid, tan to brown, slightly viscous; 40 per cent NaClO_2 weighs 14 lb. per gallon; 38 to 42 per cent NaClO_2 .

24. Sodium Fluoride. (Fluoride) Dry, white crystals or powder, free flowing, slightly hygroscopic, sometimes artificially coloured blue; NaF ; powdered 60 to 75 lb. per cubic foot and crystals 75 to 90; soluble to 0.42 lb. per gallon; dust hazard, and poison internally; 97 per cent NaF = 43 per cent F.

25. Sodium Hydroxide. (Caustic soda, soda lye)
1. Moist, white, crystalline, flakes to powder, quite hygroscopic; NaOH ; weight varies; solubility at 32° and 68°F . is 2.88 and 5.28 lb. per gallon; causes serious skins burns, slight fumes respiratory hazard; 98.9 per cent NaOH equals 76.5 per cent Na_2O : 2. Liquid, 50 per cent solution weighs 15.24 lb. per gallon; 59 to 73 per cent NaOH available.

26. Sodium Silicate. (Water glass) Liquid, opaque, syrupy, alkaline solution; $2\text{Na}_2\text{O} \cdot \text{XSiO}_2 + \text{H}_2\text{O}$, with X varying from 1 to 7.5; weight varies; solubility 20 to 55 per cent; non-hazardous; various formulae available.

27. Sodium Silicofluoride. (Sodium fluosilicate) Dry, powder, white to yellow or artificial blue, free flowing, odourless; Na_2SiF_6 ; 75 to 95 lb. per cubic foot; at 35° and 75°F . solubility is 0.43 and 0.75 per cent; dust hazard and poisonous; 98.5 per cent Na_2SiF_6 = 59.7 per cent F.
28. Sodium Sulphite. (Sulphite) Dry, white, crystals or powder; Na_2SO_3 ; 80 to 91 lb. per cubic foot; solubility from 1.2 to 2.4 lb. per gallon; non-hazardous; 93 to 98 per cent Na_2SO_3 .
29. Sulphuric Acid. (Vitriol, oil of Vitriol) Liquid, nearly colourless, very corrosive when diluted; H_2SO_4 ; 66° and 60° Be weight 18.36 and 17.16 lb. per gallon; completely soluble; will destroy flesh, ignite with organic matter, explosive when mixing with water; 66° and 60° Be = 93.2 and 77.7 per cent H_2SO_4 .
30. Sulphur Dioxide. Gas, colourless, noncorrosive when dry, very corrosive when wet, pungent odour; SO_2 ; gas weight is 2.264 times the weight of air (liquid at 68°F . = 89.6 lb. per cubic foot); solubility at 32° and 68°F . is 1.2 and 2.4 lb. per gallon; liquid burns skin, gas or liquid hazardous to eyes and internally; 99.9 per cent SO_2 .

SUBJECT:

WATER TREATMENT OPERATIONS

TOPIC: 11

Safety

OBJECTIVES:

The trainee will be able to:

1. Name three (personal) hazards common to treatment plants.
2. Recall the safety measures to follow when working in or around -
 - a) Wet Wells
 - b) Chlorine Buildings
 - c) The Laboratory
 - d) Plant and equipment during servicing.

SAFETY PRACTICES IN TREATMENT PLANTS

INTRODUCTION

The dangers associated with plant operations emphasize the need for safety practices. Physical injuries and body infections are a continuous threat and occur with regularity. Explosions and asphyxiations from gases or oxygen deficiency occur. Although infrequent at any particular location, country-wide such accidents are a daily happening. These occupational hazards may be largely avoided by the execution of safe practices and the use of safety equipment. The dangers are many and carelessness all too frequently prevails until an accident results. Then it is too late.

It is the responsibility of supervisors to acquaint themselves with the hazards associated with plant maintenance and operation and to take steps to avoid them. Accident prevention is the result of thoughtfulness and the application of a few basic principles and knowledge of the hazards involved. It has been said that the "A,B,C," of accident prevention is "Always Be Careful". One must learn how to be careful and what to avoid. With this knowledge one can then always think and practise safety.

HAZARDS

The overall dangers of accidents are much the same whether in manholes, pumping stations or treatment plants. These result from:

1. Body infections
2. Physical injuries
3. Dangerous noxious gases or vapours, oxygen deficiencies and hazardous chemicals.

BODY INFECTION

Workers in treatment plants are exposed to the hazards of water-borne diseases, including Typhoid Fever, Amoebic Dysentery, Infectious Jaundice and other intestinal infections. Tetanus and skin infections must also be guarded against.

A majority of infections reach the body by way of the mouth, nose, eyes and ears. Therefore, washing your hands is a must before eating or smoking. Wear protection gloves where possible.

Soap preparations requiring no water rinse are available for field use. The common drinking cup should be banned, each man should have and use his own.

Typhoid and Tetanus innoculations are recommended. These may be obtained free of charge from local Health Officers.

This hazard to plant personnel although very real and ever present can be largely reduced by the operator himself by following a few basic rules of personal hygiene. A few of these self applied rules are as follows:

1. Never eat your lunch or put anything into your mouth without first washing your hands.
2. Refrain from smoking while working in open tanks, on pumps, or cleaning out grit channels, etc. Remember you inhale or ingest the filth that collects on the cigarette from dirty hands. Save your smoking time for lunch hours or at home.
3. A good policy is "never put your hands above your collar when working on plant equipment".
4. Rubber or rubberized cotton gloves, rubber boots and coveralls are designed for body protection against dampness and contact with dirt, wear them at all times when working in tanks, etc.

5. Rubberized or rain suits can be worn in very wet or dirty places and can be washed off with a hose and brush, the same as rubber boots.
6. Always wear your rubber boots when working in tanks, washing down etc., don't wear your street shoes.
7. Don't wear your rubber boots or coveralls in your car or at home.
8. Always wear rubber or plastic coated gloves when cleaning out pumps, handling hoses, etc.
9. Don't just wash your hands before going home, wash your face too, there is as much of your face to carry germs as there is of your hands.
10. Wear a hat when working around sludge tanks, cleaning out grit and other channels, don't go home with your head resembling a mop that just wiped up the floor around a cleaned out pump.
11. Keep your finger nails cut short and clean, they are excellent carrying places for dirt and germs.

PHYSICAL INJURIES - First Aid

Except for minor injuries, wounds should be treated by a doctor and reported for possible Workman's Compensation. Service truck and plants must have first aid kits. It is recommended that all plant personnel should receive "St. John Ambulance" first aid instruction.

It is a "Compensation Board" regulation that any plant having five (5) or more people working as a group on any shift, one of them is required to hold a "St. John Ambulance Certificate" in first aid. Remember, no cut or scratch is too minor to receive attention.

HAZARDOUS MATERIALS

The dangers of hazardous material are dealt with later in this topic.

THE PLANT SAFETY PROGRAM

Before starting a safety program, the full co-operation and active support of management is needed. One person in the utility organization must be responsible for the program. In a small water works system, that person may be the superintendent, while in a larger organization, another person who can devote part or full time to the job can be appointed.

The next step in setting up the program is to provide for:

1. Keeping injury records
2. Identification and location of the hazards
3. Making equipment, plant arrangements and working methods safe
4. Getting employees interested in safety
5. Controlling work habits

Injury Records

The keeping of injury records is basic to a safety program. With complete records, the program is given direction and is sure of success. The records should be kept brief but must contain all pertinent data. The forms should cover such items as:

1. Accident report
2. Description of accident
3. Physician's statement
4. Corrective action taken
5. Accident analysis chart

Locating the Hazards

The person responsible for the safety program should be constantly on the alert for hazards which may cause an injury to an employee. One of the best methods of attacking this problem is to search the records for the conditions and situations that have produced injuries. Records like this show the need for a corrective program.

Many other sources of information on hazardous conditions are available. These include safety manuals, insurance company brochures, etc. They should be used freely and frequently.

Equipment, Plant Arrangements, Working Methods

Nothing prevents an accident as effectively as the elimination of the cause. To preach safety while permitting unsafe conditions will discourage the cooperation required from employees. Only when safety is integrated with the job are workers convinced that the man responsible for safety wants to prevent accidents.

Some Protective Safety Equipment

The need for protective safety equipment in an accident prevention program has proven its value many times; the program cannot be successful if any phase of accident prevention is overlooked.

Use safety equipment as it was meant to be used.

This should be compulsory during the performance of hazardous jobs.

Protect eyes and face when there is any possibility of injuries from hand tools, power tools, welding equipment, etc.

Protect feet with safety shoes to safeguard against injuries while breaking pavements, tamping trenches, handling materials, etc.

Protect head (with hard hats) to prevent serious injuries in construction, excavation or electrical work.

Protect hands (with gloves) to prevent injuries from occurring when handling materials, sharp objects, chemicals or electrical equipment.

Use air packs when hazards such as chlorine, painting or dusty areas exist.

Prevent accidents due to falls by using safety belts, scaffolds, etc.

GENERAL PLANT SAFETY

When working at the plant, observe the following common sense rules:

Keep walkways clear of loose objects such as pails, shovels, loose rope, etc.

Wipe up grease and oil *immediately*; salt or sand icy walks.

Pick up all tools, clean them and return them to their storage area.

When it is necessary to use tools in an empty tank or manhole, etc., lower them in a pail on a rope and remove them in the same way. Brooms and shovels can also be transported by rope. *Do not attempt to climb up and down ladders with your hands full of tools.*

Do not overload yourself when using stairways. Keep your load small enough to be able to see over it. Always keep one hand free to use the hand-rail.

Do not try to climb up or down a ladder or over a railing when handling a hose under pressure.

Always wear hip wader rubber boots with good treaded soles when washing down the floor of any tank. *Do not wear rubber boots with worn soles and heels.*

Always wear the rubber clothing provided when working in a narrow or confined passage where grit or sludge accumulates.

Always wear rubber or plastic coated, waterproof gloves when cleaning pumps, handling hoses, removing grit or sludge, etc.

When it is necessary to use an extension ladder to enter any empty tank, use the collector arms in the clarifiers to backstop the ladder legs. In an aeration tank, lash the ladder. Enter the tank from a walkway (not from a narrow dividing wall) and *always lash the ladder to a hand-rail.*

Always wear hard hats when working below ground level (in tanks, manholes, etc.) or under scaffolding.

Do not hang clothes on electrical disconnect handles, light switches or control panel knobs.

Replace all manhole covers and trap doors to wells. Close after using. If it is necessary to leave them open, *protect them with guard-rails.*

Use the proper tool when removing or replacing manhole covers. *Do not attempt to move or close a manhole cover with your hands.*

When working in manholes located in a street or road, post signs with blinking amber lights and red flags at each approach to the area.

Do not pull up grit-filled pails by rope when removing from tanks or wet wells. Use an "A" frame and pulley or some other type of support with a pulley. Be sure the support and pulley are fastened firmly to prevent them from toppling over during use.

Always wear a safety belt with a short rope and a safety snap when leaning out through the railings over any tank (or cleaning out spray nozzles, etc.)

Be very careful during repair work on fuel systems of gasoline engines. Close the shutoff valve from the tank and be sure there is adequate ventilation while draining the fuel system.

Check the ventilation of any enclosed or underground areas when gasoline operated pumps are to be used.

Do not refill a gas engine when in operation or while still hot. Remove spark plug from engine before cleaning out pump unit.

Building Maintenance

Periodic inspections are necessary to eliminate hazards (fire safeguards, etc.). Suggested repairs for safety should receive immediate attention. Floors, hallways, and stairways should always be well lighted, clean, orderly and free from oil, dirt and debris. Immediate repairs of hazardous electrical outlets and fixtures should be routine. Adequate sanitary facilities for employees must be provided. Hand-rails on steps and stairways should always be provided and used. *Good housekeeping must be maintained.*

Hand Tools

Hand tools are the cause of many accidents and injuries when improperly used and in unsafe condition. Therefore, use the right tool for the right job in the right way. Use protective safety equipment where there is a job hazard. Keep the work area clear of hazards, with plenty of working space for solid footing. Tools should be in good condition and used for the purpose for which they were intended.

Portable and Power Tools

All equipment should be grounded. Check wiring and equipment regularly for defects. Be very careful when using equipment in wet areas. Use protective safety equipment when operating grinders, buffers, or other tools when there is danger of flying material.

Tools and Machines

Use protective equipment when operating power equipment if there is any chance of flying objects or other injuries. Inspect all tools and equipment for safe operation. Necessary repairs or replacements should be made immediately. *Repair power tools and machinery only when the equipment is turned off.*

Welding

Use the proper protective equipment at all times. Check for fire hazards before cutting or welding in areas of inflammable or explosive mixtures. *Only authorized personnel should operate welding equipment. The Ministry of Labour requires a 2 3/4 lb fire extinguisher be fastened to the welding truck.*

Inspections of Tools and Equipment

Periodic inspections should be made of tools and equipment so that those that are broken or worn out may be replaced. *Report worn or broken equipment and be sure they are replaced or repaired as soon as possible.*

Ladders

Ladders should be inspected periodically and maintained in good order. *Use safety belts when awkward positions are necessary for the work. Do not use metal ladders for electrical work.*

Lifting

Always lift with the leg muscles instead of the back and be sure your footing is secure. Bend your knees and keep your back straight. Don't turn or twist your body when lifting. Get help if load is too heavy or awkward to handle. Use mechanical device for lifting wherever possible.

Sanitation

Washrooms, toilets, locker rooms, drinking fountains and showers that are clean, ventilated and adequately built are good for employee morale. Clean drinking water and paper cups should be available at each plant, especially if the employees are exposed to skin irritant materials.

Storerooms

Good housekeeping must be maintained at all times. Space should be well arranged to permit proper storage, handling and movement of materials. Inspections should be made regularly for fire hazards. Fire extinguishers should be in good order and easily accessible.

Working Area

A safe working area must be provided for efficient work. In the field, traffic should be controlled by the use of traffic cones, barricades, flags, etc., to protect the workmen as well as the public. In the material yard and storerooms, good housekeeping and properly planned storage and work areas must be provided for safe working practices. Shops, plants and offices should be planned for the most efficient production.

Trucks and Equipment

Routine inspections of trucks and equipment should be made. Any need for repairs should be reported and acted on as soon as possible. Only qualified and licensed operators should be permitted to use and operate vehicles and equipment. Never permit riders on trucks or other mobile equipment. Check electrical and any other hazards constantly when moving heavy equipment. All trucks should be equipped with first aid kits, fire extinguishers, and flares.

Barricades and Traffic Control

An adequate and safe work area must be protected. Sufficient traffic cones and barricades should always be carried by crews assigned to construction or maintenance work in streets. Paint barricades bright, visible colours and keep them in good condition. Be sure warning signs, flags, flares are adequate and in positions where they can be easily seen.

EQUIPMENT SERVICING

When servicing plant and equipment, Do Not:

1. Grease or oil or attempt to service any machinery while it is in operation. Pumps on automatic control must be locked out and key carried by the operator during servicing.
2. Make any adjustments to operating machinery while alone. If it is necessary to run the unit to adjust it, a second man must be present and be beside the stop and go switch.
3. Work around electrical panels, disconnects or switches alone.
4. Enter any crawl space under flooring for any purpose until the area has been ventilated. A second man should be present.
5. Service pumps and shafts in the dry wells of pumping stations, and in plants where the pumps and shafts are less than three feet apart, without shutting off all pumps and locking them out.
6. Under any circumstances, attempt to grease or service pump shafting while standing on beams, piping, loose planks, guard rails, or by leaning out, over or through guard rails. If a ladder must be used, then a second man must be present to hold the ladder steady and to provide any other assistance.

PRECAUTIONS FOR ELECTRICAL MAINTENANCE

1. Plan safety into each job. Orderliness and good housekeeping are essential for your safety and the safety of others.
2. Each employee shall be qualified both in experience and general knowledge to perform the particular electrical work which he is assigned. Outside contractor to be called in.
3. Study the job carefully to determine all of the hazards present and to see that all necessary safeguards and safety devices are provided for safe working conditions.
4. Examine all safety devices before they are used to ensure that they are in good condition.
5. In all cases where work is being performed on or close to live conductors or equipment, at least two men shall work together. When it is necessary for one to leave, the other workman shall not continue the work until the first man returns.
6. Consider the results of each action. There is no reason for you to take chances that will endanger yourself and others.
7. Satisfy yourself you are working under safe conditions. The care exercised by others can not be relied upon.
8. Wear close fitting clothing, keep sleeves rolled down, avoid wearing unnecessary articles while working on or close to live circuits or apparatus.
9. Use only approved types of rubber or leather gloves.
10. Protect yourself by placing an insulated medium between you and ground or grounded apparatus to keep any part of your body from providing a path for electrical current when working on conductors or apparatus that may be energized.

11. Use rubber mats when working on any electrical control panel or switch and disconnect boxes.
12. Open and close switches completely with a firm positive motion. Switches in a partly open position may arc or cause a flash-over with damaging results to the switch and possible injuries to the operator.
13. Open switches fully before removing fuses. To remove a fuse from a circuit carrying a current without opening the switch is particularly hazardous. Use an approved low-voltage fuse puller to remove fuses on a circuit of less than 500 volts (where no switch is provided) whether a disconnect is provided or not. Remove fuses by breaking contact with the hot side of the circuit first. Use the reverse procedure when replacing fuses. Insert the fuse in the cold terminal first.
14. Do not stand directly in front of panel to remove fuses or shut off disconnects.
15. Shut off the power when examining or making repairs or alterations on light and power circuits. When this is impractical Head Office must be contacted for further instructions before proceeding with the work.
16. Consider all electrical circuits to be dangerous. Treat dead circuits as though they were alive. This may prevent an accident as the circuit may be closed through an error of some other person.
17. Exercise extreme care when required to locate troubles on a series lamp circuit, before repairs are made make sure the power is cut off.
18. Lock or block open the control devices, open disconnect switches or remove fuses before examining, repairing or working on power circuits. After

these precautions have been taken, attach tie-up tags worded "WORKMEN ARE WORKING ON LINE." The tag shall bear the name of the workman. Tie-up tags shall remain on the opened devices until removed by the workman whose name appears on the tag. If the workman leaves without removing his tag, it may be removed only on authorization of Head Office.

19. Before working on line circuits at a point remote from the control switch, which has been tagged, it is recommended that the conductors be grounded at a point on the line between the switch and the work station.
20. Make a complete check of the circuit before applying power for the first time. This is to be done by a qualified man in charge of the repairs, all other workmen to stand off at a safe distance.

FIRE PROTECTION

Good housekeeping is the basis for fire prevention. Inspections should be made periodically and correction of fire hazards should be made as soon as possible. Consult local fire departments for recommendations.

Each operator should have first hand knowledge of fire extinguisher, its ABC rating point of contact and time of operation.

A CO₂ fire extinguisher can only be used in an open area where the chance of using up the local oxygen is minimal. Never grab the horn of the extinguisher to direct the CO₂. The gas being expelled will freeze your hand to the horn causing serious injury. There is a handle provided. Do not direct the CO₂ at anyone. To fight the fire you must approach the fire from upwind, pull the pin and aim directly on the burning area.

The approximate operating time for CO₂ fire extinguishers is as follows:

2½ lb. 10 sec. \pm 2 sec. 2. BC.
5 lb. 14 sec. \pm 2 sec. 4. BC.
10 lb. 14 sec. \pm 3 sec. 6. BC.
15 lb. 25 sec. \pm 4 sec. 8. BC.
20 lb. 30 sec. \pm 4 sec. 8. BC.

Note: The 2. BC etc., refers to the type of fires and area the extinguisher covers. (BC) indicates electrical, gas, oil type fires, "A" type are wood, paper, etc., CO₂ will not be effective on "A" type fires.

(2) indicates the extinguisher will put out a fire of not more than 2 square feet in area.

Weight indicated refers to contents only.

A Dry Chemical extinguisher can be used in any area. Approach from upwind and pull the pin, you do not have to stand as close to the fire as with CO₂. Dry Chemical will put a blanket of chemical over the fire, smothering it.

Note:

1. All extinguishers must be refilled after using no matter what amount has been used.
2. All extinguishers must be hydrostatically tested every five years.

CHEMICAL HANDLING AND STORAGE

The Occupational Health and Safety Act states that the employer is responsible for providing the necessary protective equipment and clothing for handling dangerous materials. It is the responsibility of the employee, both to his employer and to himself, to use and maintain them.

Eyewash fountains and deluge showers must be located within fifteen (15) feet of the entrance to any chemical handling area. Plenty of water should be available for washing up after handling chemicals. Protective clothing should be washed after use.

All areas where solvents or other compounds are used and stored must be well ventilated. The working area must be designed and constructed for the safety and convenience of the worker and for his efficient production. The ventilation should be by mechanical means *with the air intake drawing air from the outside*. In rooms where lime and other dry types of chemicals are used, install dust accumulators in the air discharge pipe.

Operate exhaust fans when handling any chemical whether liquid or dry.

Wear rubber boots, apron, gloves and eye shield or goggles when handling liquids. Wear nose and mouth filter masks and goggles when handling dry chemicals.

LABORATORY

1. A thorough knowledge of first aid for dealing with lab accidents is essential. Know the relevant sections of the antidote chart.
2. Wear protective clothing.
3. Practise good housekeeping. Keep all unnecessary equipment out of working areas. *Use a separate marked container for broken glass.*
4. Areas around sinks and taps should be kept clear so that chemicals spilled on one's hands or person can be washed off quickly.
5. Wipe up all spills immediately.
6. All reagent bottles must be clearly labelled so they can be identified. The date when the reagent was made up, or received, should be on the label since some chemicals, particularly nitrogen compounds, become unstable with age.

7. When diluting concentrated acids or bases, always add slowly to the water allowing time to cool. Use only heat resistant (Pyrex) glassware. When diluting sulphuric acid or when making up a solution of sodium hydroxide, cool the solution in a water bath.
8. Chromic acid cleaning solution is a mixture of sodium or potassium dichromate in concentrated sulphuric acid. It dehydrates and oxidizes most organic matter, including clothing.
TREAT IT WITH CARE!
9. Use water as a lubricant when making glass to hose connections. For vinyl tubing, hot water can be used to make the plastic more pliable. Gloves should be worn when making hose connections to glass tubing.
10. Suction bulbs should be used on all pipets. A valved type sold as a "PROPIPET" will save fumbling.
11. Combining chemicals found in the laboratory without knowing how they will react can produce unexpected and unpleasant results.
12. When disposing of any chemical in the sink, dilute with plenty of water.
13. Bottles of hazardous liquids should be stored near floor level in ventilated cupboards.
14. HASTE MAKES WASTE (and accidents). Planning can save far more time than hurrying (and produces fewer mistakes).

Characteristics of Dangerous Gases and Gas Fuels

Refer to Tables 11-1 and 11-2.

SAFETY PRACTICES IN WORK AREAS

The following paragraphs list some of the specific safety measures an operator should observe when carrying out his responsibilities in a plant.

No Smoking Areas

1. Chemical storage areas
2. Fuel storage areas
3. Wet and dry wells of plant pumping stations
4. Pump rooms
5. Tunnels having pipe galleries
6. Chlorine building
7. Manholes, tanks, reservoirs, excavations, trenches

Chlorine Buildings

1. The following signs must be posted outside the room door:
 - a) Turn on Vent Fan
 - b) Danger Chlorine Storage
2. A "Fresh Air" air pack must be located within 15 feet of room door.
3. An eye wash bath must be located within 15 feet of room door.
4. Mechanical ventilation of the chlorine room shall be sufficient to produce 30 air changes an hour taking suction from within 18 inches of the floor.
5. Operator must wear safety goggles and a pair of rubberized gloves.
6. Two operators shall be present for cylinder changing.

7. Fresh strong ammonia must be used for leak detection.
8. The chlorine room must NOT be used as a plant storage area.

Wet Wells

A wet well is classified as a confined space under Sec. 119 of the Occupational Health & Safety Act, 1978 and Regulations for Construction Projects. Before entering, the operator must:

1. Test for oxygen content using an oxygen meter. DO NOT ENTER unless the oxygen content in the atmosphere registers between 18% and 23%.
2. Test the noxious gases and vapours using a combustible gas analyzer.
3. Test for Hydrogen Sulphide using the colorimetric test. Tests for other gases may also be necessary.

The operator must also take the following precaution on entry:

1. If any atmospheric contamination is suspected, a fixed or portable vent fan of 700 cfm capacity must be used before and during entry. If no vent fan is available, a portable air pack must be worn.
2. Explosion and waterproof lighting must be used.
3. An operator with a man hoist must be located at all times at the entrance to the wet well to monitor the meters and observe the operator inside.
4. If a man hoist is not available two operators must be at the entrance.
5. A parachute type harness and lifeline and hard hat must be worn.
6. A step-through parting is required at the ladder entrance.

Dry Well

1. Vent fan shall be started before entering the pumping station and left operating continuously while the operator is in the station.
2. "DANGER PUMPS ON AUTOMATIC CONTROLLER" signs should be posted at the control panel floor level, and the pump floor level.
3. "NO SMOKING" signs should be posted at the pump floor level.
4. Lock out switches at control panel when working on any pump at any floor level.

Pump Rooms

1. "Caution Pumps on Automatic" signs must be posted.
2. Vent fans must be on.

HANDLING CHEMICALS

In handling chemicals in the water treatment process, the general safety requirements outlined earlier should be met. Operators should be aware of the hazards associated with chemicals used in a water treatment.

Alum

Wear protective dust-proof equipment (goggles and nose mask) and proper clothing when handling and storing alum. Avoid skin and nose irritations by using plenty of water when washing and bathing.

Hydrofluosilic Acid

The vapour or liquid chemical is very dangerous when it comes into contact with the eyes, skin or any part of the body, or if taken internally.

Operator must wear protective clothing and equipment consisting of long gauntlet type rubber gloves, high rubber boots or waders, short type rubber raincoat and chemical safety goggles with a plastic face shield.

Fluoride Powders

Do not let dust touch skin or inhale fumes.

Air ventilation must be at least ten (10) air changes per hour.

Operator must wear good quality coveralls, rubber boots (knee length), rubber gloves or plastic coated cotton gloves with cuffs of half a forearm length; dust proof cap and rubber apron, plastic goggles, nose mask with replaceable filters approved by the U.S. Bureau of Mines for fluorides. The filter in the nose mask should be replaced each day or more frequently if required.

Showers must be available. All rubberized clothing should be hosed down at the end of a shift.

A urine sample must be submitted by each operator to the MOH once every three months.

Empty chemical bags must be deposited in a securely tied plastic bag at a sanitary landfill. *DO NOT BURN THESE BAGS.*

Sodium Chlorite

This chemical is highly explosive if it is in contact with organic matter. Store it in a clean, cool, dry area. Keep it away from open flame or heat. A "Metal X" fire extinguisher is the only type that will extinguish this material when on fire.

Ammonia

Store cylinders in a cool, dry, ventilated place. Handle with care. An air pack should be available. In case of cylinder leaks, only trained personnel should make repairs. You must know your first aid if you handle and use this material.

Activated Carbon

Store in a dry, fire-proof space. Wear protective, dust-proof equipment (goggles and nose mask) when handling activated carbon. Do not smoke while working with or near stored material. Use plenty of water when washing and bathing.

Lime

Use protective, dust-proof equipment (goggles and nose mask) while handling lime and use a dust collecting system, if possible. Store in a ventilated, dry area. Use plenty of water when bathing and washing to prevent irritations. Consult a physician if irritation becomes severe.

Soda Ash

Handle soda ash as described for lime. See above.

Solvents

Be careful when using solvents in confined areas. The area should be well ventilated. Clean solvents from skin to prevent irritations.

Table 11-1 CHARACTERISTICS OF DANGEROUS GASES ENCOUNTERED IN SEWERS, SEWAGE PUMPING STATIONS AND SEWAGE TRT PLANTS

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY (AIR=1)	PHYSIOLOGICAL EFFECT*	MAX. SAFE 60-MIN. EXPOSURE (% BY VOL. IN AIR)	MAX. SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR)	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
CARBON DIOXIDE	CO ₂	COLORLESS, ODORLESS WHEN BREATHED IN. LARGE QUANTITIES MAY CAUSE ACID TASTE. NONFLAMMABLE. NOT GENERALLY PRESENT IN DANGEROUS AMOUNTS UNLESS O ₂ DEFICIENCY	1.53	CANNOT BE ENDURED AT 10% MORE THAN FEW MIN., EVEN IF SUBJECT IS AT REST AND OXYGEN CONTENT NORMAL. ACTS ON RESPIRATORY NERVES.	4 TO 6	0.5	- -	AT BOTTOM; WHEN HEATED MAY STRATIFY AT POINTS ABOVE BOTTOM	PRODUCTS OF COMBUSTION, SEWER GAS, SLUDGE. ALSO ISSUES FROM CARBONACEOUS STRATA.
CARBON MONOXIDE	CO	COLORLESS, ODORLESS, TASTELESS, FLAMMABLE, POISONOUS.	0.97	COMBINES WITH HEMOGLOBIN OF BLOOD. UNCONSCIOUSNESS IN 30 MIN AT 0.2 TO 0.25%. FATAL IN 4 HR AT 0.1%. HEADACHE IN FEW HR AT 0.02%.	0.04	0.01	12.5 70.0	NEAR TOP, ESPECIALLY IF PRESENT WITH ILLUMINATING GAS.	MANUFACTURED GAS, FLUE GAS, PRODUCTS OF COMBUSTION, MOTOR EXHAUST, FIRES OF ALMOST ANY KIND.
GASOLINE	C ₅ H ₁₂ TO C ₉ H ₂₀	COLORLESS, ODOR NOTICEABLE AT 0.03%. FLAMMABLE.	3.0 TO 4.0	ANESTHETIC EFFECTS WHEN INHALED. RAPIDLY FATAL AT 2.4%. DANGEROUS FOR SHORT EXPOSURE AT 1.1 TO 2.2%.	0.4 TO 0.7	0.10	1.3 6.0	AT BOTTOM	SERVICE STATIONS, GARAGES, STORAGE TANKS, AND HOUSES.
HYDROGEN	H ₂	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE.	0.07	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	-	-	4.0 74.0	AT TOP.	MANUFACTURED GAS, SLUDGE DIGESTION TANK GAS, ELECTROLYSIS OF WATER. RARELY FROM ROCK STRATA.

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 11-1

CHARACTERISTICS OF DANGEROUS GASES (CONTINUED)

GAS	CHEMICAL FORMULA	COMMON PROPERTIES*	SPECIFIC GRAVITY OR VAPOUR DENSITY	PHYSIOLOGICAL EFFECT *	MAX. SAFE 60-MIN EXPOSURE (% BY VOL. IN AIR)	MAX. SAFE 8-HR EXPOSURE (% BY VOL. IN AIR)	EXPLOSIVE RANGE (% BY VOL. IN AIR)	LIKELY LOCATION OF HIGHEST CONCENTRATION	MOST COMMON SOURCES
HYDROGEN SULFIDE	H ₂ S	ROTEN EGG ODOR IN SMALL CONC. EXPOSURE FOR 2 TO 5 MIN AT 0.016 IMPAIRS SENSE OF SMELL. ODOR NOT EVIDENT AT HIGH CONC. COLORLESS. FLAMMABLE.	1.19	IMPAIRS SENSE OF SMELL RAPIDLY AS CONC. INCREASES. DEATH IN FEW MIN AT 0.25 EXPOSURE TO 0.07 TO 0.15 RAPIDLY CAUSES ACUTE POISONING. PARALYZES RESPIRATORY CENTER.	0.02	0.002	4.3 46.0	NEAR BOTTOM, BUT MAY BE ABOVE BOTTOM IF AIR IS HEATED & HIGHLY HUMID.	COAL GAS, PETROLEUM SEWER GAS, FUMES FROM BLASTING UNDER SOME CONDITIONS SLUDGE GAS.
METHANE	CH ₄	COLORLESS, ODORLESS, TASTELESS. FLAMMABLE	0.55	ACTS MECHANICALLY TO DEPRIVE TISSUES OF OXYGEN. DOES NOT SUPPORT LIFE.	PROBABLY NO LIMIT PROVIDED OXYGEN PERCENTAGE IS SUFFICIENT FOR LIFE.	5.0 15.0	AT TOP, INCREASING TO CERTAIN DEPTH.		NATURAL GAS, SLUDGE GAS, MANUFACTURED GAS, SEWER GAS. STRATA OF SEDIMENTARY ORIGIN. IN SWAMPS OR MARSHES.
NITROGEN	N ₂	COLORLESS, TASTELESS. NONFLAMMABLE. PRINCIPAL CONSTITUENT OF AIR (ABOUT 79%).	0.97	PHYSIOLOGICALLY INERT	-	-	- -	NEAR TOP, BUT MAY BE FOUND NEAR BOTTOM.	SEWER GAS, SLUDGE GAS. ALSO ISSUES FROM SOME ROCK STRATA.
OXYGEN (IN AIR)	O ₂	COLORLESS, ODORLESS.	1.11	NORMAL AIR CONTAINS 20.9% OF O ₂ . MAN CAN TOLERATE DOWN TO 12% MIN. SAFE 8-HR EXPOSURE, 14 TO 16%. BELOW 10% DANGEROUS TO LIFE. BELOW 5 TO 7% PROBABLY FATAL.	-	-	- -	VARIABLE AT DIFFERENT LEVELS.	OXYGEN DEPLETION FROM FLOOR VENTILATION AND ABSORPTION, OR CHEMICAL CONSUMPTION OF OXYGEN.
SLUDGE GAS	-	MAY BE PRACTICALLY ODORLESS, COLORLESS.	VARIABLE	WILL NOT SUPPORT LIFE.	NO DATA. WOULD VARY WIDELY WITH COMPOSITION.	5.3 13.3	NEAR TOP OF STRUCTURE.	FROM DIRECTION OF SLUDGE.	

* PERCENTAGES SHOWN REPRESENT VOLUME OF GAS IN AIR.

Table 11 - 2

CHARACTERISTICS OF GAS FUELS

GAS	CHEMICAL FORMULA	B. T. U. CALORIFIC VALUE	SPECIFIC GRAVITY OR VAPOUR DENSITY	EXPLOSIVE LIMITS IN AIR % BY VOLUME		THEORECTICAL AIR REQUIRED FOR COMPLETE COMBUSTION	MINIMUM IGNITION TEMPERATURE ° FAHRENHEIT	MAXIMUM FLAME TEMPERATURE ° FAHRENHEIT	FLAME SPEED PER SEC.	AUTO IGNITION TEMPERATURE	
				LOWER	UPPER						
METHANE	CH ₄	913.1	0.55	5	15	9.56 TO 1	1170°	3484°	0.85	1000	
NATURAL GAS		1027	0.6	4.9	15	10.00 TO 1	1170°	3562°	0.99	1000	
11-25	PROPANE	C ₃ H ₈	2385	1.52	2.10	10.10	23.9 TO 1	898°	3573°	0.95	871

TAKEN FROM FACTORY MUTUAL'S HANDBOOK OF INDUSTRIAL LOSS PREVENTION. CHAPTER 37

SUBJECT:

PROCESS CONTROL TESTS

TOPIC:

12

Jar Tests

OBJECTIVES:

The trainee will be able to:

1. Perform a jar test.

Jar Tests

GENERAL

Jar Tests are used by operators to determine the correct dosage of coagulants and coagulant aids. They are also designed to show the effectiveness of chemical treatment in a water treatment facility. Many of the chemicals that are added to water can be evaluated on a small laboratory scale by the use of a jar test. The most important of these chemicals are those used for coagulation such as alum and polymers. Using the jar test the operator can approximate the correct coagulant dosage for plant use when varying amounts of turbidity, colour or other factors indicate raw water quality changes. The jar test is also a very useful tool in evaluating new coagulants or polymers being considered for use on a plant scale.

APPARATUS (See Figure 12-1)

- 1) Stirring machine with variable speeds from 0-100 rpm.
- 2) An illuminated base (preferred but not necessary).
- 3) 6 beakers 1500 mL.
- 4) 1 graduated cylinder 1000 mL
- 5) Pipet 10 mL graduated.

Figure 12-1

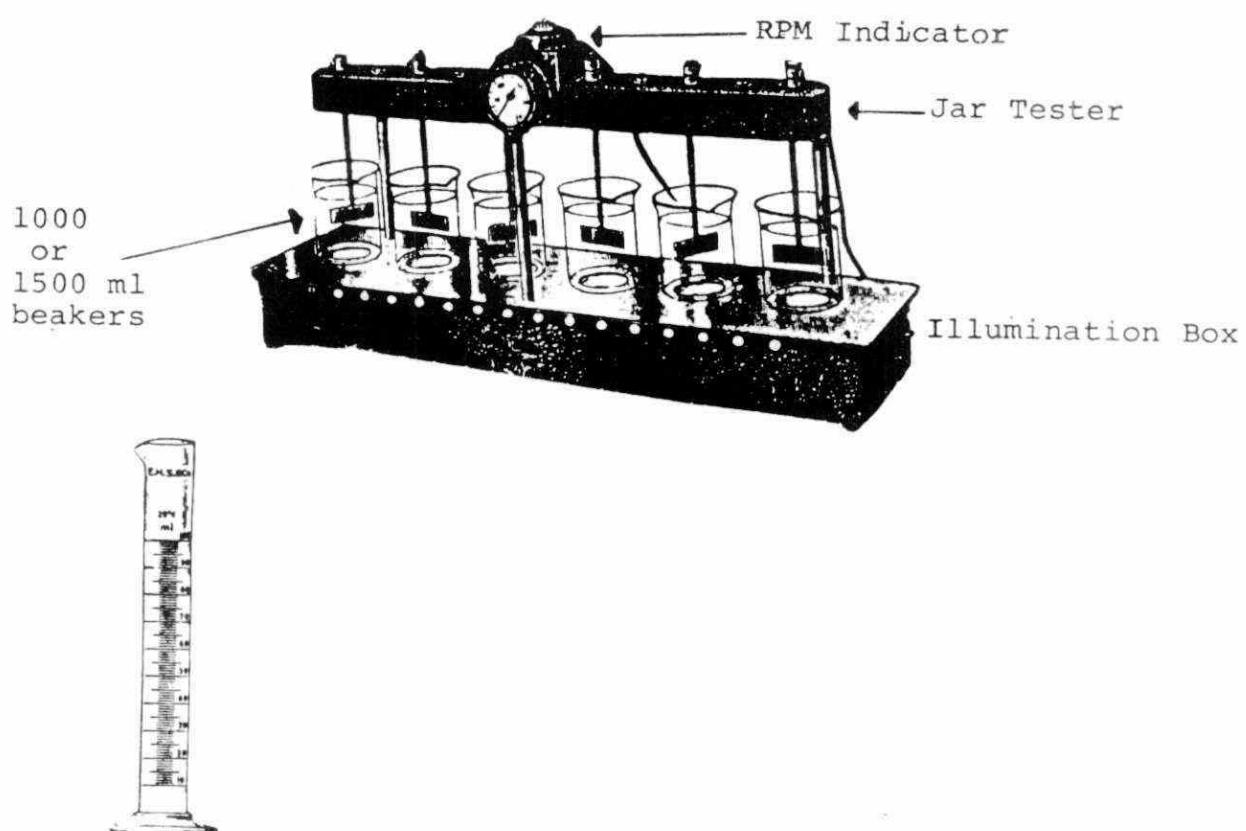
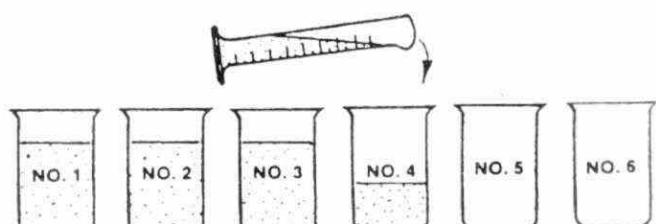
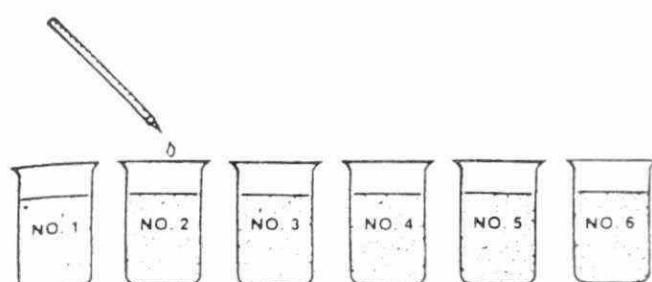


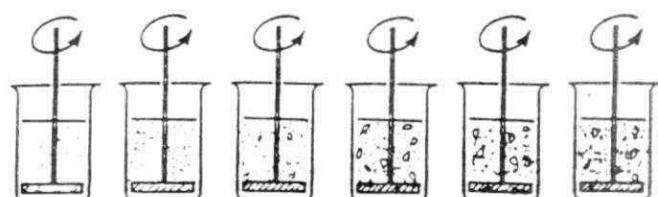
Figure 12-2



1. Add 1000 mL to each of 6 beakers.



2. Add increasing dosages of coagulant.



3. Stir for appropriate time period.
Evaluate floc quality.

- 6) Stock coagulant solution prepared from actual coagulant used in the treatment process.
- 7) Clock or timer.

PROCEDURE

- 1) Collect 8 litres of sample of the water to be tested.
- 2) Immediately measure six 1000 mL quantities and place into each of six 1500 mL beakers (Figure 12-2).
- 3) Place all six beakers on stirring apparatus.
- 4) With a measuring pipet, add increasing dosages of coagulant solution to the beakers as rapidly as possible. Select a series of dosages so that the first beaker will represent an under-dose and the last an over-dose.
- 5) With stirring paddles lowered into the beakers, start stirring apparatus and operate it for one minute at a speed of 100 rpm*.
- 6) Reduce the stirring speed for the next 30 minutes to 20 rpm*.

- 7) Observe and evaluate each beaker as to that specific dosage's floc quality. Record results.
- 8) Stop the stirring apparatus and allow samples in beakers to settle for 30 minutes*. Observe the floc settling characteristics. A hazy sample indicates poor coagulation. Properly coagulated water contains floc particles that are well-formed and dense, with clear liquid between the particles. Describe the results as poor, fair, good or excellent.

* Speeds and times should be similar to conditions in the plant.

The jar test is easy to perform but it is useless unless the operator records the data and observations he has obtained. (Figure 12-3) shows a typical data sheet used to record jar test data.

CHEMICAL SOLUTIONS

Stock solutions of coagulants, coagulant aids and other chemicals should be prepared at concentrations such that quantities suitable for use in coagulation tests can be measured accurately and conveniently. Table (12-1) relates dosages and concentrations of coagulants used in jar testing.

Table 12-1

Approx. Dosage Required mg/L	Grams/Litre to prepare	1 mg/L Added to 1 Litre Sample Equals	Stock Solution Conc.,mg/L(%)
1-10 mg/L	1 g/L	1 mg/L	1,000 mg/L(0.1%)
10-50 mg/L	10 g/L	10 mg/L	10,000 mg/L(1.0%)
50-500 mg/L	100 g/L	100 mg/L	100,000 mg/L(10.0%)



Jar Test Data Sheet

SAMPLE _____	DATE _____					
OPERATOR _____	TIME _____					
COAGULANT/COAGULANT AID USED _____						
SAMPLE DATA:						
TEMP.						
pH						
TURB.						
ALK.						
COLOR						
MIXING DATA:						
	RPM	MIN				
COAGULATION (Flash mix)						
FLOCCULATION (Slow mix)						
SETTLING						
JAR TEST DATA:						
PARAMETERS	#1	#2	#3	#4	#5	#6
COAGULANT DOSAGE						
COAGULANT AID DOSAGE						
FLOC FORMATION						
SETTLING CHARACTERISTICS						
RESIDUAL COAGULANT						
SUPERNATANT						
pH						
TURB.						
ALK.						
COLOR						

NOTES:

FIGURE 12-3

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 13

- pH

OBJECTIVES:

The trainee will be able to carry out and/or describe the methods for determining:

1. the pH of the water by visual or electrometric methods.

pH AND HARDNESS

pH

pH is a term that is used to express the level or intensity of the acid or alkaline conditions that prevail in a sample. Technically speaking, pH can be described as the logarithm of the reciprocal of the hydrogen ion concentration, but in colloquial language, it is a scale for measuring acidity in the same way as Centigrade or Fahrenheit is a scale for measuring temperature.

Soon after Hydrogen was discovered a little over 200 years ago, it became apparent that all acids contained this element, and, on neutralizing an acid with an alkaline substance, water was produced among other things. It was found that such water contained a hydrogen ion concentration of 10^{-7} mole/l. Since this same pure neutral water, when dissociated, gave one hydroxyl for every hydrogen ion present, it could be readily seen that the same concentration of the hydroxyl ion was also present (namely, 10^{-7} mole/l of hydroxyl ion).

In aqueous solutions the product of the concentrations of the hydrogen ion and the hydroxyl ion is always a constant, so that the hydrogen ion concentration of a scale starting from strong acid, going through neutral to strong alkali, would look like this:

STRONG ACID	WEAK ACID	NEUTRAL POINT	WEAK ALKALI	STRONG ALKALI
0	-1	-2	-3	-4
10	10	10	10	10
-5	-6	-7	-8	-9
10	10	10	10	10
-10	-11	-12	-13	-14
10	10	10	10	10

HYDROGEN ION CONCENTRATION IN MOLES PER LITRE

The Danish Technician S.P.L. Sorenson took the next logical step and introduced the pH symbol and scale which looked thus:

STRONG ACID	WEAK ACID	NEUTRAL POINT	WEAK ALKALI	STRONG ALKALI
0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
pH UNITS				

Before discussing pH measurement, it must be emphasized that the pH of a sample is only a measure of the level of acidity or alkalinity in a sample, (i.e. degree of ionization) and not a measure of total acidity or alkalinity.

If a decinormal (1/10) Sulphuric acid solution, and a decinormal Acetic acid solution are titrated one at a time, against the same alkali solution, they both have the same neutralizing potential. However, if pH determinations are made on both of them, the sulphuric acid has a pH of approximately 1, whilst the acetic acid has a pH of about 3. This happens because the latter has a lower degree of ionization, hence its pH is higher.

METHODS OF pH MEASUREMENT

Visual

1. In General

Dyes (Indicators) which change colours at certain pH ranges are added to the sample which has been placed in a Nessler tube or Comparator cell. The colour produced is measured in a Nesslerizer or Comparator against standard coloured glass discs.

Visual methods of determining pH are subject to error in the range of ± 0.1 pH units. This error could stem from one, or any combination, of the following factors:

- a) The human factor, i.e. poor judgment combined with questionable eyesight.
- b) Accepting a reading made at either end of the range of the standard disc (only mid-point of the range is used).
- c) Waters with low dissolved solids (hence low buffering capacities) do not give the right intensities of developed colour with the indicator.
- d) Colour in the water makes matching difficult.
- e) Wide variations in sample temperature of the glass standards affects intensity of colour.
- f) Inaccurate addition of the recommended quantity of the indicator to the sample. (Quite critical in some cases).

The use of indicators accurate for pH can only be considered useful when the following conditions apply:

- a) Measurement of pH is not too critical, i.e. ± 0.1 pH error is within the tolerance required.
- b) Lack of technical knowledge, or practical experience of personnel prohibits the introduction of electro-metric methods in making pH measurements.

2. Reagents and Apparatus Required:

B.D.H. Lovibond Nesslerizer

2 x 50 ml Nessler Tubes

Discs containing permanent glass
colour

Standard 0.2 ml Pipettes

<u>pH Indicators</u>	<u>pH Range</u>
Bromo Cresol Purple	5.2 - 6.8
Bromo Thymol Blue	6.0 - 7.6
Phenol Red	6.8 - 8.4
Cresol Red	7.2 - 8.8

3. Procedure

Select the disc and indicator so that the pH of the sample to be measured falls near the midpoint of its range.

- a) Place 50 mls of the sample in each of the two Nessler tubes.
- b) Using the tube as a blank put it in the left hand compartment of the Nesslerizer, i.e. the part under the glass standards.
- c) Add 0.2 ml of indicator to the other Nessler tube, mix it well and place it in the right hand compartment.
- d) Facing the instrument towards a North window, rotate the disc in the hinged lid and take a reading when a colour match is obtained.

Electrometric

1. Principle of Operation

A measurement is made of the millivoltage that is produced, when a sample and a couple of electrodes of a special type are set up as a galvanic cell. The number of millivolts produced depends on the level of acidity in the cell system.

2. Method of Operation

Several varieties of pH meters are in use. (See Figure 12-1). The basic method for the operation of such instruments can be summarized as follows:

- a) Turn the instrument on and wait until it is warmed up.
- b) Set the temperature at which the pH is to be measured.
- c) Calibrate the instrument with a standard Buffer Solution (while stirring).
- d) Remove the buffer and rinse the electrodes well.
- e) Place the electrodes in the sample and while stirring read the pH.
- f) Remove the sample, rinse the electrodes well and keep them immersed in distilled water.

3. Important Points to Remember

- a) Always keep the electrodes in distilled water when the pH meter is not in use.
- b) Measure at room temperature when most precise measurements are required.
- c) The pH of the buffer used to calibrate the instrument should always be as near as possible to the pH of the samples being measured.

- d) A check buffer which differs at least by 2pH units should always be kept at hand to check the calibration buffer. pH4 buffer is recommended for calibrating and pH7 for checking, or vice versa, whichever one is nearer the sample. On a good meter the reading on the check buffer should not be more than ± 0.02 pH units.
- e) pH4 buffer is the most stable buffer and pH9 is the most unstable buffer.
- f) The level of saturated Potassium Chloride (KCl) in the calomel reference electrode should always be higher than the level of the liquid that is being measured for pH. A few crystals of KCl should always be visible in the electrode.
- g) If the glass electrode has been stored in a dry condition it should be immersed for 4-6 hours in an 0.1 N Hydrochloric acid at room temperature. This procedure should also be carried out when the electrodes become sluggish.
(Note: 0.1 N Hydrochloric Acid = 9 mls concentrated Hydrochloric acid in 1 litre of distilled water.)
- h) The most common defect that causes poor pH results is a badly scratched or cracked membrane (i.e. the glass bulb at the end of the glass electrode). Cracks may occur if the membrane is just only rubbed against the bottom or sides of a beaker.

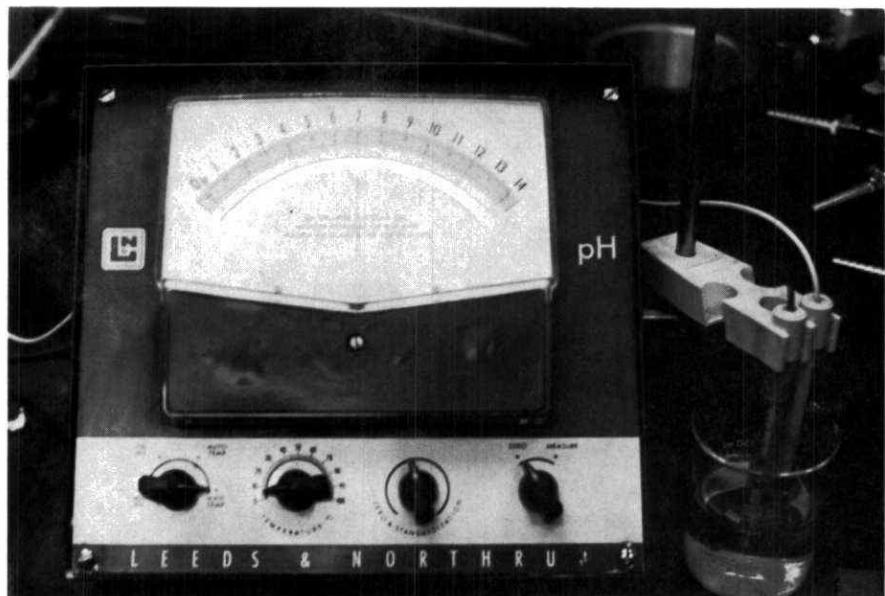
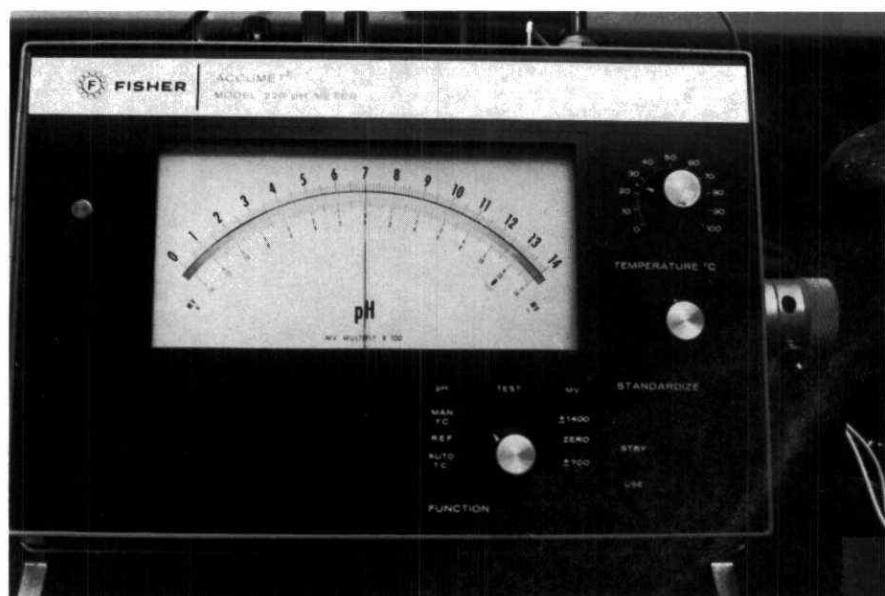


Figure 13-1 pH Meters

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 14

Tests to Determine Physical
Parameters - Colour
- Turbidity
- Taste & Odour

OBJECTIVES:

The trainee will be able to describe
and/or demonstrate:

1. The use of the Lovibond Nesslerizer
for colour determination.
2. The use of the Hach turbidimeter for
turbidity determination.

TESTS DETERMINING PHYSICAL PARAMETERS

GENERAL

The chemical processes that raw water may have to undergo in order to make it esthetically pleasing, reasonably palatable, and safely consumable, depend upon a number of variable chemical parameters which are responsible for giving each raw water its own individual characteristics. The diversity of types of water stems from the close contact it has had with varying geological basins, human pollution, and (decaying and growing) vegetation.

From the standpoint of the consumer, the physical parameters are the only ones he can readily observe with his unaided senses and upon which he bases his judgment on the effectiveness of the treatment that is given to the water that he consumes in his every day living. Thus this topic considers the laboratory procedures related to colour, turbidity and settleable solids.

COLOUR

Water is colourless by itself. When it leaches out high concentrations of iron and manganese from certain types of terrain, or organic substances from decaying vegetation, it takes on a brownish tint. Colour is a common constituent of some surface waters, and it can be attributed to the presence of non-toxic complex organic compounds.

Definition of Colour

When 1 mg of Platinum present as chloroplatinate is combined with the appropriate amount of Cobalt Chloride, and they are dissolved in one litre of distilled water, then the ensuing colour from this standard is considered to be 1 HAZEN UNIT.

Analytical Technique for Colour Determination

1. Apparatus Required

Lovibond Nesslerizer, with discs containing glass standards. See Figure 2, Page 14-4.

2. Procedure

- a) Fill one of the tubes supplied with the instrument to the 50 mL mark with the sample.
- b) Place it in the right hand compartment of the instrument (i.e. under that part of the disc without the glass standards).
- c) Fill the second tube with distilled water, and place it in the other compartment.
- d) Face the instrument towards a north window (or switch on the illuminating white light that can be obtained with the instrument, as an accessory).
- e) Rotate the disc containing the colour standards until a match is obtained. Note the number appearing in the aperture on the top of the instrument. This number is the result in Hazen Units.

3. Points to Remember

- a) When colour is caused by suspended matter, the analysis sheet must include the comment "APPARENT COLOUR" directly after the result.
- b) If the colour is caused by a material that is in solution, then the words TRUE COLOUR should follow the result.
- c) The colour test is quite susceptible to human interpretation and error. It is difficult to differentiate in single numbers, but more in ranges of 10. The operator should be more concerned about the trends towards greater than lesser density.

- d) If a request is received for a true colour determination on a sample that obviously contains suspended matter which contributes in some degree to its colour, under no circumstances should the sample be filtered, because adsorption on the filtering medium might result in a lessening of the true colour. In such cases centrifuging of the sample is the only permissible way of separating the suspended matter from it.
- e) Should the colour sample be darker than 70, which is the maximum reading that can be taken on the disc supplied with the instrument, it is permissible to make dilutions with good distilled water to bring the colour into a readable range. In this case, the result obtained must be multiplied by the dilution factor. However, in such cases discs with lighter ranges are available and their use is preferable.
- f) As a cautionary note, those with eye glasses that are affected by intensity of light may have difficulty obtaining an accurate colorimetric reading.

N.B. Experience has shown that the colour value obtained is often only valid for the pH at which the determination was made. If the pH is either raised or lowered, the intensity of the brownish colour very often becomes darker or lighter. Good practice, therefore, demands that when a colour determination result is submitted, the pH should also be recorded on the report.



COLOUR DISK

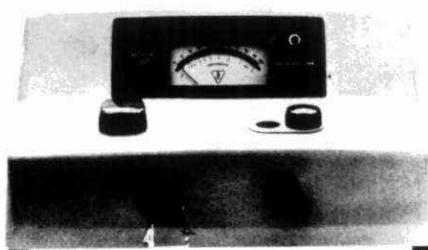
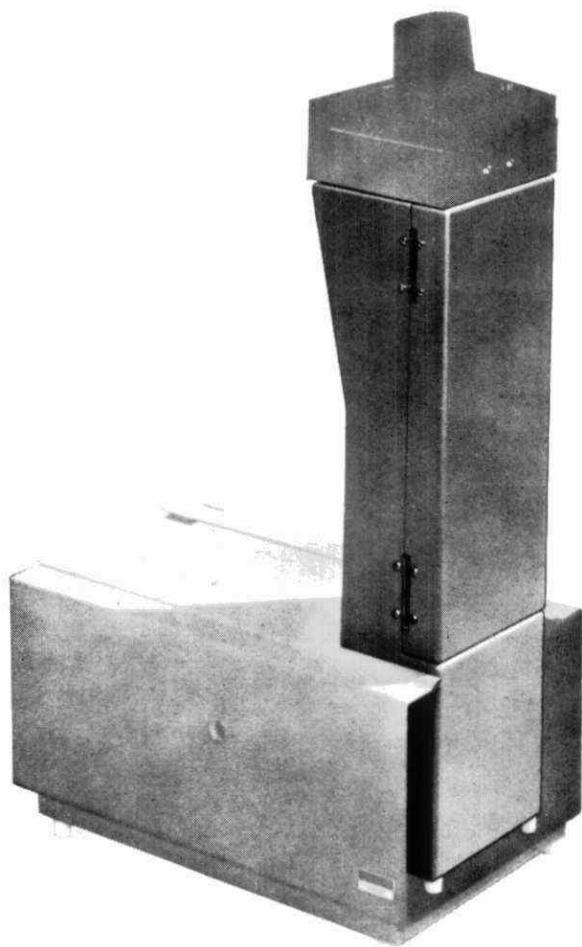


Figure 14-1 SPECTRONIC



BDH LOVIBOND NESSLERIZER
WITH LIGHTBOX

Figure 14 - 2



Figure 14 - 3

HACH TURBIDIMETER 2100A

TURBIDITY

Definition

Haze or turbidity in water is caused by suspended particles which interfere with the passage of light through the water. Depth of visibility which is curtailed, decreases as the concentration of the suspended matter increases.

Units of Measurement

There are two units currently used for the expressing or recording of turbidity concentration. They are the following:

- Jackson Turbidity Unit (JTU) sometimes called the Formazin Turbidity Unit (FTU), and Nephelometric Turbidity Unit (NTU), when Formazin or some other polymer is used as the calibrating material.

$$1 \text{ JTU} = 1 \text{ FTU} = 1 \text{ NTU}$$

Based on findings, optical units seem to be the most appropriate way of expressing turbidity concentration. The most misleading unit is ppm. The implication of this unit is that the weight of the suspended material causing the turbidity is actually known. This is certainly not true when a variety of materials compose the suspension and their percentage concentration of the total suspension is varying continuously. In such a case the relative densities of the materials together with their individual concentrations would have to be known at any given moment in order to arrive at a true ppm value; which would only be valid for that moment. The only time that the ppm scale is correct is when the material that has been used in calibrating the scale is precisely the same as the suspension of the sample being measured, and this must include the particle size distribution of the suspension.

Methods of Measurement

1. Absorptiometric

Measurement of the optical density of the sample at a wavelength that provides maximum sensitivity for this type of determination. See Figure 14-1.

Although the presence of a haze in water does not always mean that the water is unfit for drinking, it can be regarded as visually offensive, and it definitely presents an optical problem if not a health hazard. Thus, it can be readily recognized that optical units are a more meaningful way of expressing this parameter, in order to assess the magnitude of the problem.

2. Nephelometric (Greek: Nephel-Cloud)

- a) Measurement of the intensity of scattered light by the particles in suspension. The usual angle for measuring the scattered light is at 90 degrees to the incident light. This method of measuring opacity is the most sensitive way of determining the concentration of suspended material in low turbidity treated waters. Instruments incorporating this principle are recommended for use at water

plants, because they are the only ones that measure with great accuracy any water that has a very high clarity. Such instruments are very sensitive and can measure down to 0.03 FTU quite readily, and with great precision. Some plants that periodically have taste and odour problems usually incorporate carbon filters into their treatment system. At such plants, should the treated water become fouled by carbon leakage from a faulty filter, the Nephelometric method cannot be used and a switch to the Absortiometric method becomes necessary in order to measure the carbon particles in suspension.

b) Hach 2100A Turbidimeter (Figure 14-3)

The Hach 2100A Turbidimeter, that has been evaluated by the Ministry of the Environment, uses the Nephelometric principle. This instrument is reliable and performs with great accuracy, if determinations are carried out in the manner described below. This procedure includes several important points not found in the manual issued with the instrument.

c) Important Points to Remember - in determining Turbidity with the Hach 2100 and Hach 2100A.

- (i) Check that the instrument is optically aligned with the template provided. If alignment is needed, consult the factory supplied maintenance manual.

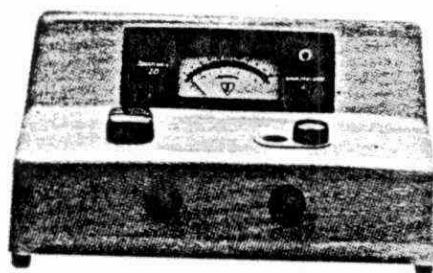


FIGURE 14-2 SPECTRONIC



FIGURE 14-3
HELLIGE TURBIDIMETER

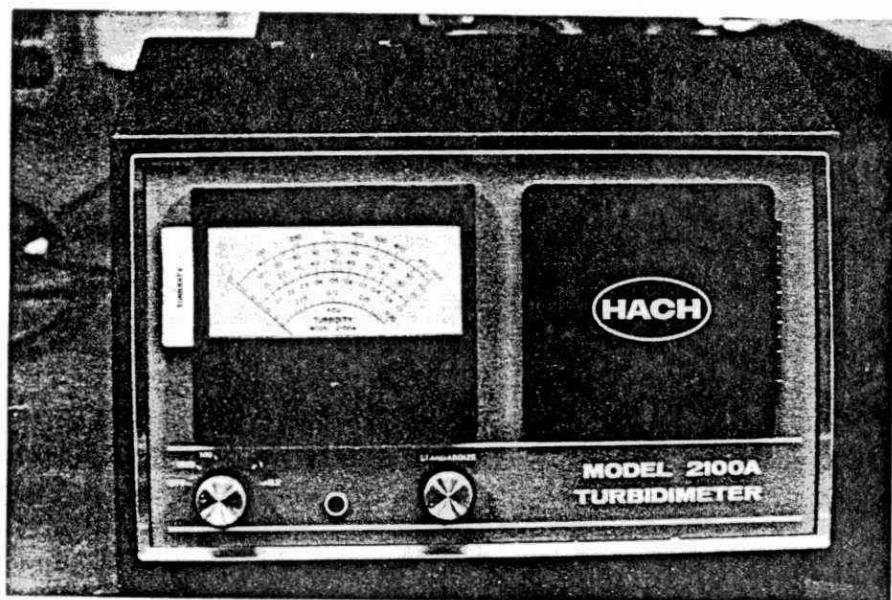


FIGURE 14-4 NEPHLOMETER
(HACH TURBIDIMETER 2100A)

- (ii) The temperature of the instrument goes up when the instrument has been recently switched on. This causes the calibration point to slowly drift downward. An operating plateau is reached about 100 minutes after switching on the instrument.
- (iii) Always keep the range switch on 0 when using Model 2100 and on 1000 when using Model 2100A, or else the photo sensitive equipment could be damaged.
- (iv) Always rotate the range switch in a way that will avoid a lower scale than the sample requires coming into play. If this happens, the indicator needle hits full scale and the instrument goes out of calibration.
- (v) Beware of de-gassing samples or covering the cell with greasy fingers.
- (vi) Always check the cell, using very low turbidity water to see how clean it really is.
- (vii) Standardize the instrument with newly precipitated Formazin Standard Solutions at all ranges. If adjusting is necessary, consult the service manual.
- (viii) Standardize calibration rod against Formazin.
- (ix) Never forget to use the cell riser on the 100 and 1000 FTU ranges.
- (x) Never leave a sample in the instrument.

(d) Operation Steps

- (i) Standardize the instrument with the standards supplied by Hach.
- (ii) Check the cell for cleanliness with low turbidity preserved water

(Calibrate as frequently as possible, especially after instrument has recently been switched).
- (iii) Fill the clean cell with the carefully stirred sample. Dry and polish the outside with Kimwipes. Place the cell in the instrument and cover it with the light shield.
- (iv) Set the range at which the reading is to be made and take a reading.
- (v) Return the range to 0 on model 2100 and to 1000 FTU on model 2100A.
- (vi) Remove the sample and rinse the cell and replace it in the instrument.

TASTE AND ODOUR

General

Taste and odour problems are usually caused by both organic and inorganic materials that have inadvertently entered the raw water source. When this happens, our first objective should be to identify the material that is giving rise to the problem and then close off or slow down its further entry into the water system. The next step is to try to eradicate any material that is residual in the system, by carbon filtration if the contaminant is organic, or by flocculation and filtration if it is inorganic.

Method of Measurement

A panel of at least five non-smoking people should be selected, who have not eaten anything or drunk anything stronger than water for at least two hours. The location chosen should be free from all odours, and the panel should work individually, if space allows.

Procedure (see Appendix 1)

1. The following series of dilutions: 2,4,8,16,32, 64,128 and 256 should be made from the sample using odourless water (i.e. Carbon Filtered Tap Water).
2. Place 250 mls of the above dilutions in 500 mls clean stoppered flasks.
3. The diluted samples should be warmed to 60°C, and starting with the highest dilution they should be passed around among the panel members; each member must shake the flask before trying to detect an odour.
4. The greatest dilution at which at least three members of the panel concur about the presence of an odour, should be taken as the Threshold Odour Number.

The procedure for the determination of taste threshold number is the same as the one for the odour threshold number, except that the dilutions are not warmed to 60°C, but are tasted at room temperature (70°F).

THRESHOLD ODOUR TESTPurpose:

- (1) to check on the odour quality of raw and treated waters
- (2) to control odours in the plant
- (3) to determine dosages of chemicals required for treatment
- (4) to evaluate effectiveness of different treatment methods
- (5) to determine or trace the source of contamination

Principle

Substances causing tastes and odours in water are present in such minute quantities and are of such varied nature that chemical analytical methods are not very reliable. Therefore one's own sense of taste and smell have been found to be the most suitable for detecting and measuring the odour quality of the water. Since the sense of smell is more convenient to use, it has become the basis of the "Threshold Odour Test" by which the odour intensity in the sample of water is measured.

Threshold odour number represents the number of times or the dilution ratio to which a sample of an odour-bearing water must be diluted with odour free water to reduce the odour so that it is just detectable.

Apparatus Required for the Test

6 to 8	500 - ml Erlenmeyer flasks with ground glass stoppers (S32)
2	thermometer, 0° - 110° C
1	250 - ml graduated cylinder
1	100 - ml " "
1	50 - ml " "
1	25 - ml " "
1	10 - ml or 5 - ml graduated pipette
1	large electrical hot plate
1	water bath
1	odour-free water generator

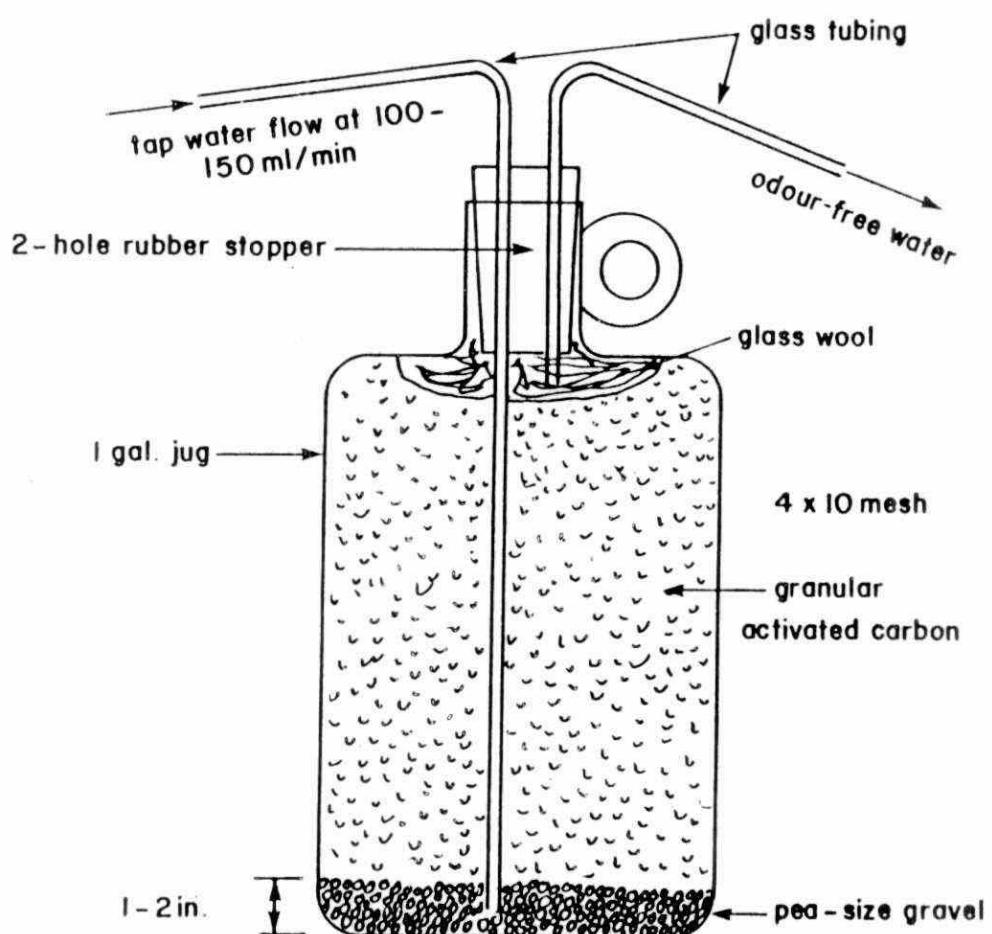


FIGURE 14-5 ODOUR-FREE WATER GENERATOR

Preparation of Odour-Free Water

To conduct threshold odour and taste tests, an adequate supply of odour-free water should be available. Odour-free water is required for preparing the dilutions of the odour-bearing samples, for reusing all glassware free of odours and for use as a blank in the test.

Odour-free water should be prepared as needed because it will absorb any odours that may be in the room. Most tap waters are suitable as sources for the preparation of odour-free water. This is done by passing tap water through the odour-free generator at the rate of 0.1 liter per minute. This is approximately 20 minutes of contact time with the carbon.

Procedure

Determine the approximate range of threshold odour number

1. Add 200 ml, 50 ml, 12 ml, and 2.8 ml of the sample water to each separate glass-stoppered Erlenmeyer flasks. Each flask should be numbered.
2. Add odour-free water to make a total volume of 200 ml in each flask.
3. Add 200 ml of odour-free water to another glass stoppered flask which will be used as the reference for comparison.
4. Heat all of the flasks to 60° C in the water bath or on the hot plate. (Considerable time can be saved by preheating the odour-free water to 60° - 65° C)
5. Shake the flask containing the odour-free water. Remove the stopper and sniff the vapours.
6. Do the same with the flask containing the least amount of odour-bearing water (undiluted sample) and note whether it has an odour and if so, describe what type.
7. If the odour can be detected in this flask then more dilute samples must be prepared.
8. If the odour cannot be detected in the first diluted sample, repeat this procedure — first sniffing the flask with the odour-free water — with the flask containing the next higher concentration of the odour-bearing water.

9. Continue this process until the odour is clearly detected.

Determine the actual T.O.N. of the odour-bearing water.

- 1) Based on the results obtained in the preliminary test, prepare a set of dilutions using the following table as a guide.

DILUTIONS FOR VARIOUS ODOUR RANGES			
Sample Volume in Which the Odour First Noted			
200 ml	50 ml	12 ml	2.8 ml
Volume of Sample to be Diluted to 200 ml			
200 ml	50 ml	12 ml	2.8 ml
140	35	8.3	2.8 ml
100	25	5.7	2.0
70	17	4.0	1.4
50	12	2.8	1.0

- 2) Dilute each sample of odour-bearing water to 200 ml with odour-free water.
- 3) Add 200 ml of odour-free water to two or more flasks to be inserted into the series as a reference and a blank for comparison.
- 4) Mark each flask with a number or a letter.
- 5) Heat all the flasks to 60° C and then arrange them so their odour is unknown.
- 6) Shake the flask containing the odour-free water. Remove the stopper and "sniff" the vapours.
- 7) Take up the other flasks one by one, remove the stopper and "sniff" the vapour comparing each one with the one containing the odour free water.
- 8) Record the results for each flask as "positive" (+) if an odour was observed and negative if no odour was observed.

Example

code	1	2	3	4	5	6	7
ml sample	12	0	17	25	0	35	50
Response	-	-	-	+	-	+	+

9) The dilution containing the smallest volume of odour bearing water which gives a positive reaction is the threshold odour number (T. O. N.). In the above example, the first detectable odour occurred when 25 ml of odour-bearing was diluted to 200 ml with odour-free water.

$$\text{Therefore } \text{T. O. N.} = \frac{200}{25} = 8$$

The following table gives the dilutions and their corresponding T. O. N. values

THRESHOLD ODOUR NUMBERS CORRESPONDING TO VARIOUS DILUTIONS			
Sample Volume Diluted to 200-ml	T. O. N.	Sample Volume Diluted to 200-ml	T. O. N.
200	1	12	17
140	1.4	10	20
100	2	8.3	24
70	3	5.7	35
50	4	4	50
40	5	2.8	70
35	6	2.	100
25	8	1.4	140
20	10	1.0	200

Precautions

1. Selection of persons
2. Selection of test area where the tests are being conducted

3. Cleaning of the glassware
4. Precautions in making dilutions
5. Elimination of residual chlorine in the treated water

References

- (1) STANDARD METHODS for the Examination of Water and Wastewater, 15th Edition.
- (2) Taste & Odour Control in Water Purification
West Virginia Pulp & Paper Co. (Chemical Division) 230 Park Avenue, New York, N.Y. 10017 (1966). This publication is available on request from Standard Chemical Limited
60 Titan Road,
Toronto M8Z 1J8

SUBJECT:

PROCESS CONTROL TESTS

TOPIC: 15

- DPD Method
- Spectrophotometer Method
- Amperometric Titration Method

OBJECTIVES:

The trainee will be able to:

1. demonstrate and carry out the procedures for determining the chlorine residual using the DPD method with the Nesslerizer and comparator;
2. determine the chlorine residual of a given sample using the Spectrophotometer Method
3. Recall the principle of operation of the Amperometric titrator.

CHLORINE TESTING PROCEDURES

DPD METHOD

Principle of the Method

Research in chlorine chemistry has resulted in the development of a very simple procedure for the determination of its free and total residual. There are two commonly used methods to perform the DPD test. One is the use of a colour comparator, using compressed tablets which when dissolved in the chlorinated sample produces a pink shade of varying degrees depending on the strength of chlorine present. By using two different tablets, a free and total chlorine residual can be determined.

The other method is the use of a spectrophotometer. This unit uses a photocell to compare the colour intensity created by the presence of chlorine. It has a high degree of accuracy.

Equipment and Reagents Required

1. DPD tablets for Comparator and Nesslerizer
 - a) Nos. 1 & 3 together for total chlorine residual.
 - b) No. 1 for free chlorine.
2. Comparator with Standard Lovibond Discs
 - a) 3/40 A disc covers the range 0.1 to 1.0 mg/l chlorine.
 - b) 3/40 B disc covers the range 0.2 to 4.0 mg/l chlorine.

These discs require 13.5 mm cells or test tubes. A dulling screen must be used.

3. Nesslerizer with Disc

NDP covers the range 0.05 to 0.5 mg/l. This disc must be used with a dulling screen and 50 ml tubes.

Procedure

1. Compactor

a) Determining Total Chlorine Residual

- (i) Place a 13.5 mm cell or test tube containing sample only in the lefthand compartment, behind the colour standards of the disc.
- (ii) Rinse a similar cell with the sample, and fill the cell or tube up to the mark with it.
- (iii) Into this cell or tube drop one No. 1 and one No. 3 tablet (or one No. 4 tablet, which is No. 1 and No. 3 combined).
- (iv) Allow tablets (or tablet) to disintegrate until effervescence ceases.
- (v) Mix rapidly to dissolve the remains of the tablet.
- (vi) Place the cell in the righthand compartment of the Comparator.
- (vii) After 2 minutes, match the cells by holding the Comparator facing a good source of diffused north daylight and revolve this disc until the correct standard is found. NEVER LOOK INTO THE SUN.
- (viii) The figure shown in the indicator window represents mg/l of total chlorine residual present in the sample.

b) Determining of Free Chlorine Residual

- (i) Prepare tubes as outlined above for total chlorine residual, one "blank" tube and one with just a few drops of sample.
- (ii) To the tube with sample, add one No. 1 tablet only.
- (iii) After disintegration, add water up to mark, and
- (iv) Mix as before and match at once. This gives *free chlorine residual*.

Note: It is permissible to determine TOTAL CHLORINE on the same sample by continuing as follows: add one No. 3 tablet, mix and stand for 2 minutes. The colour then read off represents *total chlorine residual*.

c) Determining Combined Chlorine Residual

Total Chlorine Residual - Free Chlorine Residual
= *Combined Chlorine Residual Value*.

2. Nesslerizer

Follow exactly the same procedure for the Comparator, with the following exceptions:

- a) Use 50 ml instead of 10 ml.
- b) Use special Nesslerizer DPD tablets.

Note: It must be emphasized that the readings obtained by means of the B.D.H. Lovibond Nesslerizer and disc are only accurate provided that Nesslerizer glass is used which conforms to the specification employed when the discs are calibrated, namely, that the 50 ml calibration mark shall fall at a height of 113 ± 3 mm, measured internally.

3. False Colour due to Interferences

- a) The only interfering substance likely to be present in water is oxidized manganese from potassium permanganate in those water plants that use it for taste and odour control.
- b) Test the unchlorinated water for colour development and use as a Blank.
- c) *All glassware used must be very thoroughly rinsed after making a test, since only a trace of potassium iodide will cause chloramine colour to develop. Handling the tablets should be avoided. By shaking one tablet into the bottle top it is a simple matter to use the top for conveying the tablet to the Comparator cell or Nessler tube.*

SPECTOPHOTOMETER METHOD

Principle of Operation

The spectrophotometer as shown in Figure 15-1 is a single-beam analytical instrument that measures concentrations of particular substances in water colorimetrically. These substances are reacted chemically, causing the colour to vary in intensity in proportion to that concentration. A variable interference light filter is used to select the wavelength of light seen by the photocell.

This instrument gives a high degree of accuracy for the measurement of free and total chlorine residuals.

Procedure

1. Spectrophotometer Setup

- (a) The standardizing solution (usually the original water sample) is placed in the cell holder and the lid closed. Only clean, dry sample cells should be placed in the instrument and with either clear side toward the light source.

- (b) Ensure that the chlorine meter scale has been inserted and the Wavelength Dial adjusted to 530 mm.
- (c) To zero the instrument, the light switch is held in the ZERO CHECK position while the ZERO ADJUST control is used to obtain a zero transmittance reading (needle aligned with the mark at the extreme left of the arc).
- (d) The instrument is standardized by setting the light switch to ON and using the LIGHT CONTROL to obtain a meter reading of 0 mg/l (extreme right mark of the scale arc). The instrument does not need to be zeroed each time a test is performed, but frequent checks of the zero adjustment are recommended.

2. Sample Analysis

Determining Free Chlorine Residual

- (a) Fill cell with water to be tested to the 25 ml mark.
- (b) Add the contents of one DPD Free chlorine Reagent Powder Pillow and swirl to mix. A pink - red colour will develop if chlorine is present. To allow time for proper colour development, wait at least 3 minutes, but not more than 6 minutes.
- (c) Place sample in cell holder and read the mg/l chlorine.

NOTE

If the sample temporarily turns yellow when adding the DPD reagent or reads above the 2 mg/l mark the chlorine concentration is too high for the meter scale and a sample dilution is necessary.

Determining Total Chlorine Residual

- (a) Using the same sample add the contents of one DPD total chlorine Reagent Powder Pillow. Swirl to mix. Wait at least 3 minutes
- (b) Place sample in cell holder and read to mg/l chlorine.

Determining Combined Chlorine Residual

Total Chlorine Residual - Free Chlorine

Residual = Combined Chlorine Residual Value.

AMPEROMETRIC TITRATION METHOD

General

The most accurate methods of measuring free and combined chlorine residuals is through oxidation-reduction titration procedures. Such methods require the use of internal indicators or electrometric devices employing a suitable electrode system to show when reactions are completed. Amperometric titrators employing rotating platinum electrodes have been developed for such purposes. See Figure 15-2.

Phenylarsene oxide is the reducing agent normally used as the titrating agent. It reacts with free chlorine residuals at pH 6.5 to 7.5 in a quantitative manner.

By conducting a two-stage titration, with the pH adjusted at about 7 and then at about 4, it is possible to measure separately free chlorine residuals and combined chlorine residuals.

Titrator - Principle of Operation

Titration is a method used to determine the concentration of a substance in a solution. This is accomplished by adding the smallest amount of a reagent (of known concentration) required to cause a neutralizing effect, in reaction with a known volume of the test solution. A graduated vessel (or burette) is used to add the reagent to the known volume of test solution until the chemical reaction between the two is completed. The point of completion is indicated by either (a) adding an indicator dye and watching for a change in its odour or (b) stopping at a predetermined end point on a pH meter or microammeter.

A direct current potential is impressed across two nodal metal electrodes immersed in a measuring cell containing the sample of the solution to be tested. Any

flow of current between the electrodes is directly proportional to the quantity of halogen (such as chlorine, bromine, or iodine) in the sample. The presence of a current is indicated on a microammeter at the top of the instrument.

A reagent (also called a titrant) is added in small doses to the sample, and reacts chemically with the chlorine present in the solution, thereby neutralizing a portion of the chlorine. As more titrant is added, more chlorine is "removed", causing the current flowing between the electrodes to diminish as indicated by the microammeter pointer moving down the scale. Finally, sufficient titrant is added to react with all the chlorine, and no further decrease in current is possible. This is called the *end point*.

The amount of chlorine residual present in the test solution is determined by noting the number of millilitres of titrant used to attain the end point. Then:

$$\text{mg/l of chlorine} = \text{mls of titrant that have been used.}$$

Procedure

1. Filling the Burette

Make sure the titrant (phenylarsene oxide solution) fills to the zero mark.

2. Titration of Free Chlorine Residual

- a) Fill the solution jar with 200 ml of sample.

- b) Add 1 ml pH 7 buffer solution.

- c) Fill the microburette with the titrant (phenylarsene oxide solution) to the zero mark.

- d) Titrate by adding phenylarsene oxide solution and observe current changes on the microammeter. As long as addition of phenylarsene oxide produces a definite decrease in current, free chlorine residual is present.

- e) The end point is just passed when a very small increment of phenylarsene oxide no longer causes a decrease in current.
- f) The burette is then read and the last increment of titrating solution is subtracted from the reading to give a value representing the free chlorine residual.

3. Titration of Total Chlorine Residual

- a) To the sample remaining from the free chlorine titration add 1 ml potassium iodide solution and then 1 ml pH 4 buffer solution IN THAT ORDER.
- b) Titrate with phenylarsene oxide solution to an end point, just as above for the free chlorine residual. It is most convenient NOT to refill the burette but simply to continue the titration.
- c) After concluding the titration and having found the end point, subtraction of the last increment again gives the amount of titrating solution actually used in reaction with the chlorine.
- d) If the titration was continued without refilling the burette, this figure represents the total chlorine residual. Subtracting the free chlorine residual from the total gives the combined chlorine residual, or
$$\begin{aligned} &\text{Total Chlorine Residual} - \text{Free Chlorine Residual} \\ &= \text{Combined Chlorine Residual} \end{aligned}$$

Note: It is essential to wash the apparatus and sample cell thoroughly to remove iodide ion and acetate buffer after this determination, in order to avoid inaccuracies if the titrator is subsequently used for free available chlorine determination.

e) If desired, the determination of the total chlorine residual and the free chlorine residual may be made on separate samples. If only the value for total chlorine residual is required, it is permissible to treat the sample immediately with 1 ml potassium iodide solution followed by 1 ml pH 4 buffer solution. The titration is carried out with phenylarsene oxide solution as described on page 15-8 (2(c)).

Monochloramine and Dichloramine Differentiations

It is often desirable to differentiate between the monochloramine and dichloramine portion of the combined chlorine residual in a sample solution. This differentiation is accomplished in the following manner:

1. Perform the procedure outlined in Procedure for the Titration of Free Chlorine Residual. Note the reading in ppm (free chlorine).
2. Add 4 to 5 drops of potassium iodide, 5% solution to the sample jar. If monochloramine is present, the ammeter pointer will deflect to the right.
3. Titrate to the "end point"; note the reading in ppm.
4. Add 1 dropper of pH 4 buffer solution and add 1 dropper of potassium iodide, 5% solution to the sample jar. If dichloramine is present, the ammeter pointer will again deflect to the right.
5. Titrate to the "end point"; note the reading in ppm.

The difference between the readings obtained in step 1 ("free" chlorine) and step 3 preceding, represents the monochloramine component.

The difference between the readings obtained in step 3 and step 5 represents the dichloramine component.

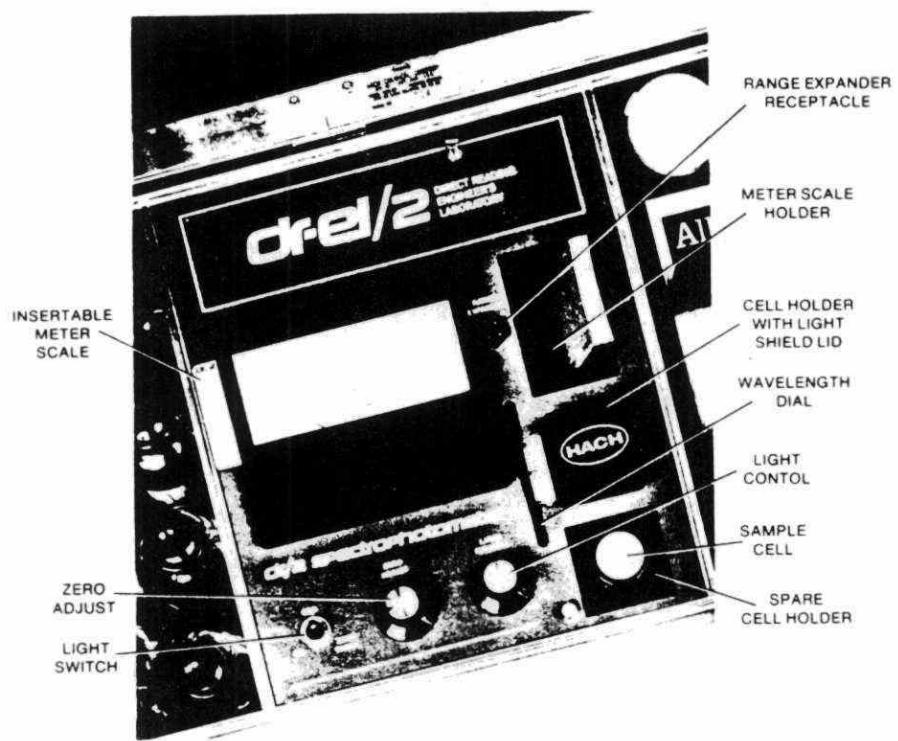


Fig. 15-1 STANDARD SPECTROPHOTOMETER

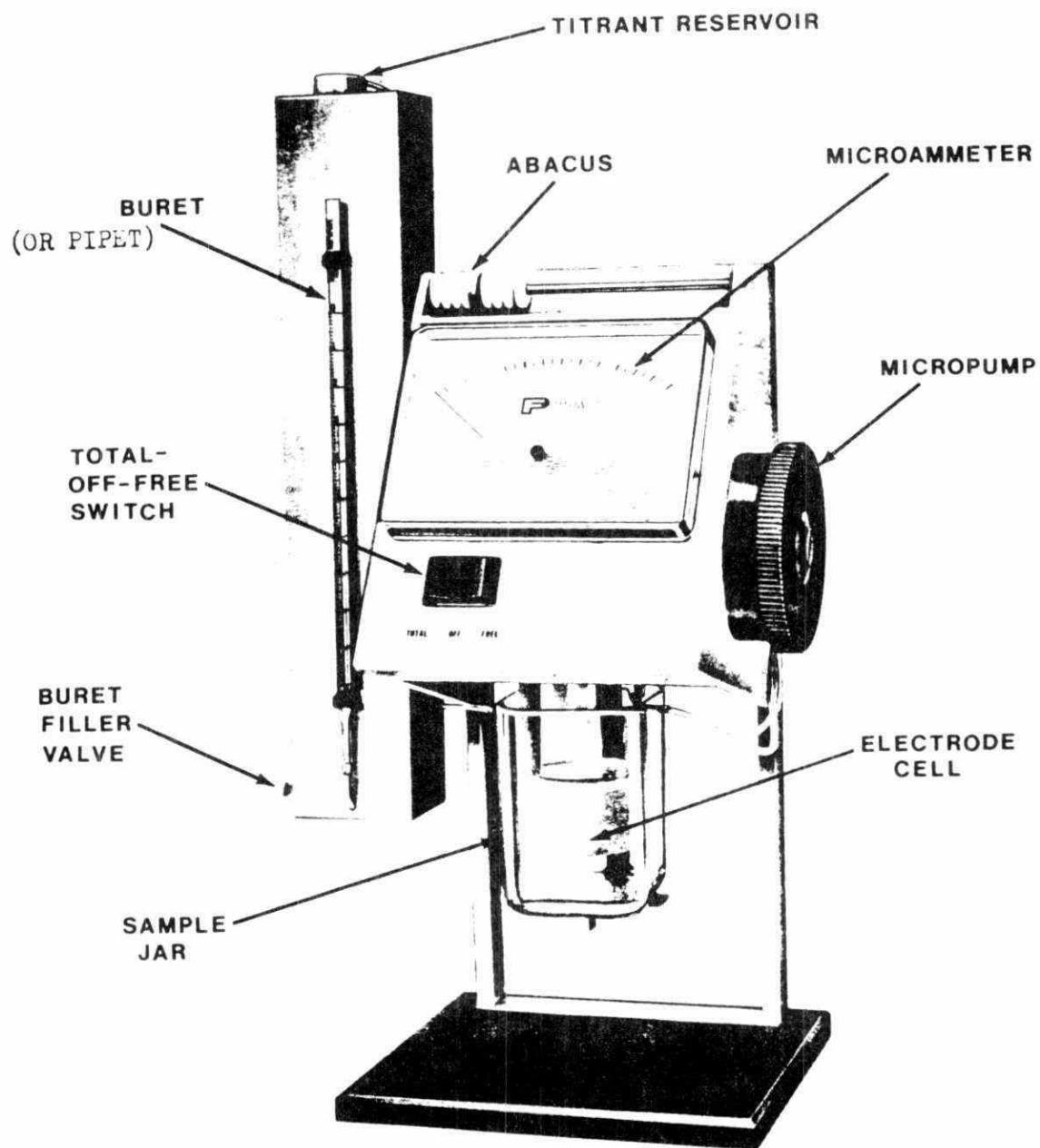


Fig. 15-2 Amperometric Titrator
(Courtesy Fischer & Porter)

GLOSSARY OF TERMS

The following definitions are intended only as aids in the study of this manual.

absorption -

The taking up of one substance into the body of another.

ABS -

Abbreviation for Sodium alkyl benzene sulfonate.

adsorption -

- (1) The adherence of a gas, liquid or dissolved material on the surface of a solid.
- (2) A change in concentration of gas or solute at the interface of a two-phase system.

aeration -

- (1) The bringing about of intimate contact between air and a liquid by one or more of the following methods:
 - a. spraying the liquid in the air,
 - b. bubbling air through the liquid,
 - c. agitating the liquid to promote surface absorption of air.
- (2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc. to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water.
- (3) Relief of the effects of cavitation by admitting air to the section affected.

air gap -

The distance between the lowest opening of a pipe supplying water to a tank or plumbing fixture and the flood-level rim of the receptacle.

algae -

Tiny plants, usually living in water and often green in colour.

algicide -

Anything applied to kill or control algae.

anionic -

Relating to negatively charged ions.

aquifer -

Porous, water-bearing formation of rock, sand, or gravel.

artesian aquifer -

An aquifer where the water is under pressure and will rise to a higher elevation if afforded an opportunity to do so.

backflow -

The backing up of water through a conduit or channel in the direction that is opposite to normal flow.

bacteria -

Single-celled microscopic plants living in soil, water, organic matter or the bodies of plants or animals.

backwash -

The method used to clean filter media by reversing the water flow.

booster station -

A pumping station in a water distribution system, used to increase the pressure in the mains on the discharge side of the pumps.

chlorine demand -

The difference between the amount of chlorine added to a water or wastewater and the amount of chlorine residual left after a certain length of time.

chlorine residual -

The amount of chlorine still left available after a certain length of contact time.

clear well -

Reservoir for storing filtered water.

coagulants -

In water and wastewater, chemicals used to thicken finely divided suspended solids into groups for easy removal.

coagulation -

In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

coliform -

A group of bacteria normally living in the intestines of man and animals and are also found elsewhere in nature. They are pollution indicators in water supplies.

colloidal -

Too finely divided to settle; requiring coagulation, biochemical action, or membrane filtration for removal.

combined chlorine residual -

The concentration of chlorine combined with ammonia as chloramine or as other chloro-derivitives, yet is still available to oxidize organic matter or carry on disinfection of water.

cone of depression -

A cone-shaped hollow made in a water table as water is drawn from a well.

contact basin -

A basin used to put water or wastewater in contact with chemicals or other materials; for example, a chlorine contact chamber.

contamination -

The presence of microorganisms, chemicals, or wastes that make water unfit for use.

diatomaceous earth -

A fine soil made up mostly of the skeletal remains of diatoms.

diatoms -

Single-celled microscopic algae that grow in or on water and have skeletons of silica.

disinfection -

Destruction of disease causing microorganisms by physical or chemical means (chlorination or boiling of water).

distribution system -

A system of piping, canals, and associated equipment used to distribute a water supply to consumers.

drawdown -

The lowering of a water level in a well or a tank.

effluent -

In wastewater treatment, wastewater or other liquid, partially or completely treated or in its natural state, flowing out of a reservoir, basin, treatment plant, or industrial treatment plant, or part thereof

enzyme -

A protein that promotes a chemical reaction, enabling it to continue at body temperature.

filter cake -

Dewatered sludge or sediment.

filter media -

The material through which water or wastewater is filtered.

filtration -

The process of passing a liquid through a filter to remove suspended solids.

floc -

Small jelly-like masses formed in a liquid by adding a coagulant.

flocculation -

The collection of coagulated suspended solids into a mass by gentle stirring.

flocculation aids -

Materials added to liquid to form flocs.

flocculator -

Mechanical equipment used to encourage the formation of floc in liquid.

hydrologic cycle -

The movement of water from the atmosphere to the earth and back to the atmosphere through precipitation, infiltration, storage, transpiration, evaporation etc.

hydrolysis -

A chemical process of decomposition using the addition of water. Also, the process solid matter goes through to become liquid.

indicator bacteria -

Coliforms that point to the presence of intestinal pathogens.

influent -

Water or wastewater flowing into a treatment plant or any of its units.

injection wells -

Wells created to recharge groundwater.

inorganic -

Made of matter that is not plant or animal.

ion exchange

A chemical process in which ions from two different molecules are exchanged.

ionizing -

Creating ions by adding electrons to, or removing them from, atoms or molecules.

iron bacteria -

Bacteria that use iron as food and discharge its compounds in their life processes.

leaching -

Percolating liquid through soil or other solids to remove the soluble ingredients.

metabolism -

The process in which food is used and wastes are formed by living matter.

MF -

Membrane filter (used in bacteriological lab test)

microbes -

Microscopic organisms, especially pathogenic bacterium.

micro-organisms -

Minute organisms, either plant or animal, invisible or barely visible to the naked eye.

MPN -

Most PROBABLE Number (used in bacteriological lab test).

nutrient -

Food for the growth of organisms.

organic -

Made of matter that is plant or animal.

ozonization -

The act or process of charging or treating with ozone. Also, the conversion of oxygen into ozone. Used for disinfection purposes.

pathogenic -

Disease-producing bacteria.

permeable -

Having pores or openings that permit liquids or gases to pass through.

pH -

The measure of the acid/alkaline balance, expressed on a scale of 0 to 14, with 7 being neutral; 7 to 0 increasing acidity, and 7 to 14 increasing alkalinity.

pressure head -

A measure of the pressure exerted by a fluid.

pseudomonad -

Short rod-shaped bacteria, some of which live on dead or decaying organic matter, or cause disease.

pumping level -

The height where water stands in a well during pumping.

reducing agent -

A substance that causes the loss of an electron.

retention time -

Detention time; the length of time that water or wastewater is held in a unit for any treatment.

septic -

Anaerobic (decomposition without oxygen).

spores -

Walled, single to many-celled reproductive bodies of microorganisms, able to produce new organisms directly or indirectly.

staining -

Colouring specimens for microscopic study. Also, colouring or discolouring anything.

static level -

The height of a water surface when groundwater is not being removed.

supernatant -

The liquid standing above a sediment. In sludge digestion, the liquid standing between the sludge at the bottom and the scum at the top.

surface water -

All water found on the surface of the earth.

suspended solids -

- (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.
- (2) The quantity of material removed from water or wastewater in a laboratory test, as prescribed in "Standard Methods for the Examination of Water and Wastewater" and referred to as non-filterable residue.

titration -

The method finding how much of something is in a solution by measuring how much of something else is needed to cause a chemical change.

total solids -

The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per litre.

transpiration -

The process by which plants return water to the atmosphere.

turbidity -

A condition in water caused by suspended matter; murkiness.

volatile solids -

The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 550°C.

water hammer -

Loud blows caused by moving water against the sides of its containing pipe.

watershed -

An area that drains into a particular body of water or water course.

weir -

A dam or enclosure in water or wastewater used to raise the water level or change the direction of its flow; with notches or a crest, it measures the flow.

well head -

The top of the well.

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